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Does mirror curvature influence the timing of driver action? A real-world study.

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Abstract

In critical driving situations, such as performing a lane change manoeuvre, we have the choice of looking in the driver-side mirror or the center rear-view mirror. The former is convex in most European countries, the latter is planar. Is there a difference in the perception of required acceleration depending on whether the convex driver side rear view mirror or the planar centre rear view mirror is used for the estimate? We report a real-life within-subjects experiment to compare estimates of the required acceleration to pull out in front of a car approaching them on the left lane with 4 different closing speeds. Confidence judgments of these estimates were also collected. The average data did not reveal an effect of mirror type on acceleration or confidence estimates. However, when comparisons were made on an individual basis, the planar center mirror led more often to larger acceleration values than did the convex driver-side mirror.

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1. Introduction

Nonplanar rear-view mirrors have become a part of the standard equipment in cars on the European market (Carstengerdes, 2007). They are known to be useful tools for increasing the field of view to the rear and are reported to reduce the number of accidents during lane change manoeuvres (Luoma, Sivak & Flannagan, 1995 and 2000). Nonplanar mirrors used in passenger cars are either spherical-convex, or aspheric. While planar mirrors have plane surfaces and therefore provide an accurate duplication of the real world, convex mirrors have surfaces that are portions of uniform spheres: They therefore provide a minified and distorted image of reality for the merit of increasing the field of view to the rear by decreasing the blind area. The latter can be defined as ‘the area around a vehicle [. . .] that is not visible to the operators, either by direct line of-sight or indirectly by use of internal and external mirrors’ (Beaupre J., Hause, M. & Hammer, B., 2003). Aspheric mirrors on the other hand have a spherical inboard section and an outboard section that is progressively more curved: While diminishing the blind area even more they also provide a laterally squeezed image of reality (Carstengerdes, 2007).

Recent european passenger car models often feature aspheric or convex driver side rearview mirrors (Carstengerdes, 2007), convex passenger side rearview mirrors, and planar centre rearview mirrors. While Driving instructors teach their pupils to use both the centre mirror and the driver side mirror to estimate the distance and speed of approaching cars in lane changing manoeuvres to the right (Hartig & Klammerer, 2004), there is surprisingly little research on how mirror use and convexity affect distance and speed judgements of drivers. An increased field of sight to the rear is an obvious advantage of nonplanar mirrors, however decreased image size and distortion might lead to the overestimation of distances and relative speeds of cars approaching from behind.

2. Mirrors

2.1 General effects of mirrors

Research on general effects of mirrors on perception has shown that people have a biased knowledge about mirror reflections leading to difficulties in predicting at what point the reflection of static objects would become visible to them (Croucher, Bertamini & Hecht, 2002; Bertamini, Spooner & Hecht, 2003, and Hecht, Bertamini & Gamer, 2005): Subjects approaching a mirror parallely expect to see their own reflection sooner than it is the case and thus overestimate the size of the reflected area. This is found with a variety of methods such as paper and pencil tests, fake mirrors, computer simulations with or without animation. In addition, there is a high tolerance for incorrect reflections and distortions which is not improved with expertise or the correct knowledge about the physical laws of reflection.

2.2 Distance estimates of stationary objects

Research on distance estimates through mirrors have yielded quite consistent results:

Flannagan, Sivak and Traube (1996) focussed their study on learning and adaption processes in distance estimates featuring different mirror types. Subjects made distance judgements of a stationary car viewed by either a planar, aspheric, or convex mirror. They underwent a pre-test phase without feedback on distances, a training phase with feedback and a post-test phase without feedback. The use of a planar mirror led to underestimation of distances through all phases. The aspheric mirror group showed a slight overestimation in the pre-test phase and a slight underestimation over all other phases. However, it provided the most accurate estimates. The convex mirror group showed a large overestimation in the pre-test phase, but adapted quickly during the training phase approaching the level of underestimation from the aspheric mirror group in the post-test phase. Misestimations weren’t as large as predicted by visual angle, pointing to the conclusion that other variables might contribute to the process. Nonplanar mirrors lead to larger distance estimates compared to the planar mirror. However, the use of a planar mirror lead to underestimation of distances.

A study by Carstengerdes (2007) could confirm this finding to some extent: Distance estimates through a planar mirror were significantly smaller than through a nonplanar mirror, with no significant difference between aspheric and convex mirrors and nonplanar mirrors being more accurate than planar.

Similarly, Higashiyama, Yokoyama and Shimono (2001) found that distance estimates increased linearly with the increase of the real distance of reflected objects but virtual images in a convex mirror were perceived to be farther away than those in a plane mirror.

In a study by Hecht and Brauer (2007), participants made distance and spacing estimates using either a planar or different types of convex mirrors. Errors in distance and spacing estimates showed a trend to be larger with decreasing mirror radius but contrary to previous findings, the impact of mirror type on distance or spacing estimates failed to reach significance. However, similarly to previous research, distances were significantly underestimated using planar mirrors, while convex mirrors yielded quite accurate results. In addition, convex mirrors led to significantly more variance in distance and spacing estimations, with spacing estimations being affected more clearly. Increased convexity led to increased variability in the distance estimates, implying that participants made larger errors in both directions.

2.3 Time-to-contact estimates of approaching objects

On the subject of mirror reflections of moving objects like approaching cars, research has yielded some controversy: Does curvature affect time-to-contact estimates or is it taken into account in the perception process? Time-to-contact (TTC) estimates are judgements of the exact time to an upcoming collision with an approaching object. The TTC (or Tau) theory proposed by David Lee (1976) implies that peoples' time-to-contact judgements are independent of distance, speed or acceleration info and therefore should not be compromised by the curvature of nonplanar mirrors. The theory suggests that time-to-contact is computed through the relative rate of expansion of an approaching object's retinal image. This rate of expansion is called Tau. In a lane changing manoeuvre a driver might change the lane only if Tau hasn’t reached a critical value yet.

However, many studies yielded results that contradict Tau theory. In a simulated driving experiment using a filmed view into rear-view mirrors of different radii with cars closing at different speeds, Fisher and Galer (1984) found that the judgement of the last perceived moment to safely carry out a driving manoeuvre (LPMS) is shifted backward in time when using convex mirrors: A decrease in curvature increased TTC estimates with the minimum safety margin (the time margin between perceived TTC and LPMS) being halved between the flat and the 600 mm-radius mirror. Also there was evidence that the difference in speed between the observer's vehicle and the closing vehicle has an effect: Even in the flat mirror condition there is a decrease in minimum safety margins as speed differences between cars increase. In a second semi-dynamic experiment with a stationary car and similar film material, Fisher et al. examined changes in the continuous visual sensation of distance caused by reducing the radius of curvature. The difference in distance estimates between different curvatures increased as the approach speed increased, with smaller radii being linked to longer perceived distance especially in the last three seconds before perceived time-to-contact.

Per contra, Carstengerdes (2007) found an underestimation of perceived time-to-contact compared to real time-to-contact for aspheric, convex and plane mirror types and across all distances in a real life semi-dynamic experimental setting. The largest underestimation was found for planar mirrors, followed by aspheric and convex mirrors. Also, there was a significant difference in time-to-contact estimates between the planar and the convex mirror. Further analyses revealed that subjects’ time-to-contact estimates were more dependent on perceived distance than on speed.

Another contradiction to Tau theory was found by Hecht and Brauer (2007) in their study with time-to-contact estimates of computer simulated approaching vehicles. Mirror type and display size were manipulated in six conditions: a direct view of the monitor, an indirect view via a planar mirror, an indirect view via a convex mirror (800 mm), and two conditions with a direct view but reduced display size with the same visual angle as the planar and the convex mirror. Subjects’ time-to-contact judgments were only accurate in the direct viewing condition with the original display size. All other conditions lead to overestimation of time-to-contact judgements. Since the convex condition lead to more accurate judgements than the matching direct viewing condition (with the same visual angle) while there was no difference between the plane viewing condition and the matching direct viewing condition, it could be argued that there is a separate processing of image size (visual angle) and convex distortion. The smallest visual angle caused the biggest delay in response. Thus, visual angle seems to be more critical for time-to-contact judgements than curvature. Hecht and Bauer concluded that “It might be better to use a convex over a planar mirror provided the image size remains the same”.

Recent research on time-to-contact judgements via nonplanar or planar mirrors implies that additional processes could influence time-to-contact judgements. Hecht and Savelsbergh (2004) talk about further processes that could modify the initial Tau estimate suggesting variables such as perceived size, size change, binocular perception and the change of an object’s shape.

2.3 Study approach

The current study aims at investigating whether subject’s estimates of required acceleration to safely change the lane in front of a car approaching them from behind vary depending on whether an convex[1] driver-side rear-view mirror or a planar centre rear-view mirror is used for their estimates. In addition, the effect of mirror type on subject’s confidence is examined. With the findings about time-to-contact estimates through different mirror types being quite contradictory, the following study aims at shedding some light on the question if the effect of mirror type is eminent enough to be found in a real life setting.

[1] Strictly speaking the driver's side rear-view mirror was aspheric, that is a small outer portion of shorter radius was blended into the main portion of larger-radius convexity. As observers used the main portion for their task, we use the term convex.

3. Method

3.1 Participants

The sample consisted of 20 subjects (10 female,10 male). Most of the participants were students at the Johannes Gutenberg University of Mainz. Their field of study was either classified as natural science (40%, 8 participants) or as social science (55%, 11 participants). Subjects were uninformed of the study's purposes and knew only that they would participate in an perception experiment featuring car mirrors. Their age ranged from 21 to 26, the mean being an age of 23 years, *sd* = 1.47. All except one student had a driver's license. All participants had normal or corrected-to-normal vision. The mean driving experience was 60.75 months (*sd* =19.8).

3.2 Apparatus and Stimuli

The experiment was conducted at the Johannes Gutenberg University parking facility "Dalheimer Weg" on two adjacent lanes that were separated by a 0.6 m wide stripe consisting of visibly darker concrete blocks. Each lane was 3 m wide (including the 0,3 m portion that was marked). A semi-dynamic situation was used in the experiment: Subjects sat in a stationary car (A) and were approached from the rear by the test car (B), watching the rearward scene either through the planar centre rear-view mirror or the convex driver-side mirror. The two cars used in the experiment were a VW Polo N9 (A, stationary car) and a VW Golf IV (B, test car). The stationary car (A) was parked on the right driving lane, at 0.5 metres from the separating line (figure 1). The starting position of the test car (B) was on the adjacent left lane at 62.13 metres behind the rear of car A. The test lane was subdivided into an acceleration track (31.7 metres), a test track (20.66 metres), and a deceleration track (13.66 metres). The end of the acceleration track and the test track were marked with orthogonal lines using white adhesive tape (width 5 cm), the end line of the acceleration track being dashed. The end of the test track was marked at 9.77 metres behind the rear of car A. The test car was driving with the headlights turned on. The experiment was conducted during daytime.

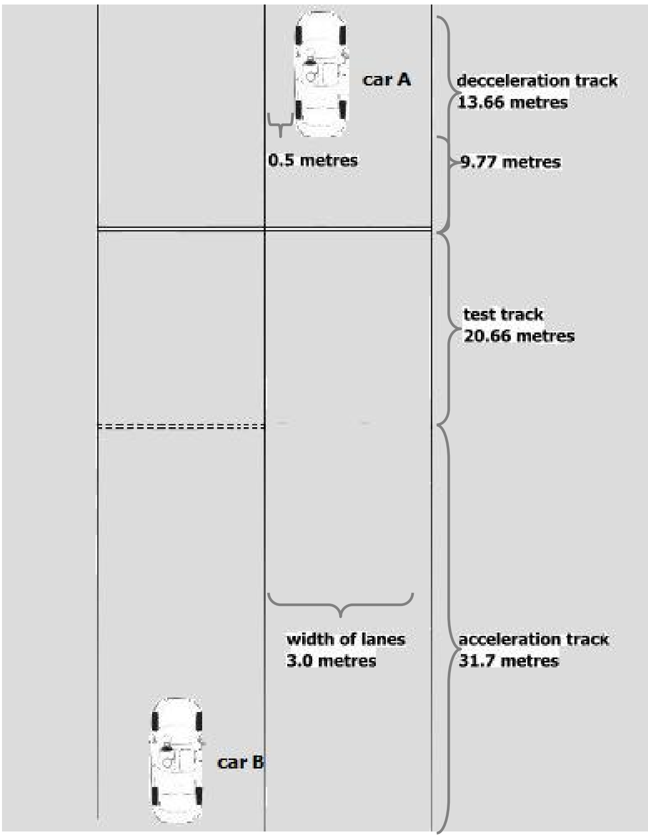

Figure 1. Experimental set-up showing the position of the stationary car A and the test car B on the test lanes.

The subject’s head position was adjusted using a pendulum that was 20.6 cm long and fixed to the car's dome at 22.8 cm from the leftmost position of the dome and 41 cm its front. Subjects leaned with their back against the car seat and their head against the headrest and adjusted their seats so that the pendulum was positioned at the root of the nose but still hung vertically. To guarantee the same visibility for the marked lines for both mirror types the headrest of the rear seat behind the driver’s seat was removed in car A.

The mirrors used in the experiment were the original VW Polo 9N mirrors (see appendix pictures). The surface of the convex driver side rear view mirror can be approximated to a rounded off trapezoid (with the sides a = 14 cm, c = 11 cm, b = 9 cm , d = 10.5 cm, height up to 9.2 cm). The convex inward section had a radius of r = 2000 mm ± 270 mm. The radius of the aspheric section can be described by the formula defined in European Parliament directive 2003/97/EG

(2003). However, subjects used the convex section to solve the task, since only a very small portion of the scene was reflected in the aspheric section. The planar centre rear view mirror had a nearly rectangular shape with a width of 23.2 cm and a height of 6 cm.

During the study the test site including the two lanes and the adjacent parking lots were roped off to avoid other vehicles from parking there, as these could have altered the visual field. The surface of the test lanes was grey cobblestones, the concrete divider between the two lanes being a darker grey than then the rest of the ground.

Subjects were handed a test sheet consisting of a single sheet of written instruction text, eight separate sheets corresponding to the 8 separate trials, and one sheet containing additional demographic questions, questions about driving experience and questions concerning the preference of mirror type used in driving manoeuvres. Each of the eight trial sheets indicated which of the two mirrors should be contemplated to make the estimates. On each trial sheet participants were asked to specify on a 10 point rating scale (1 = minimum acceleration, 10 = maximum acceleration) to what amount they would accelerate just about to succeed to change lanes without a collision. They were additionally asked to estimate how confident they were of their acceleration estimates on a 4 point rating scale with 1 signifying “not confident” and 4 signifying “confident”. No information was given about the sequence or amount of approaching speeds.

3.3 Study design

<u>Independent Variables:</u>

Two within-subjects factors were complemented with two between-subject factors. The within-subjects factors were mirror type (convex vs. planar) and approaching speed (10 km/h, 20 km/h, 30 km/h, 40 km/h). The between-subject factors were sequence of approach speeds (20-40-10-30 vs. 30-10-40-20) and sequence of mirror use (four trials convex + four trials planar vs. four trials planar + four trials convex).

Dependent variables

After each of the 8 speed trials subjects estimated the least amount of acceleration necessary to succeed to change the lane without collision, and then stated how confident they were about their acceleration estimate.

Additional dependent variables were age, gender, field of study, possession of a driver's licence, driving experience in months, mirror type generally used during lane changing manoeuvres (driver side mirror, centre mirror, none of them), perceived reliability of mirror information (best in driver side mirrors, best in centre mirrors), preference of mirror type during the experiment (driver side mirror, centre mirror, both), driver side mirror type in the car most frequently used (aspheric, convex, planar)

3.4 Procedure

Subjects were handed the test sheet and told to read the instructions carefully. The instructions suggested that subjects would participate in a perception experiment in the field of traffic psychology. Subjects would be sitting in the driver seat of car (A) and watch 8 trials of car (B) approaching them from the rear on the adjacent left lane. In half of the trials they would be watching the scene through the centre rear-view mirror, in the other half through the driver-side rear-view mirror. Subjects were told to avert their eyes from the scene just at the point when car B would arrive at the nearer white line with its front bumper. After each trial, subjects would make an acceleration estimate and a confidence estimate, the acceleration estimate signifying the least amount of acceleration required to just change the lane without collision. Subjects were told to make estimates as precisely as possible, but still spontaneous. The instruction suggested that due to engine power of car A a safe change of lane would be hypothetically possible. Subjects were instructed to read prior to each trial through which of the two mirrors they should contemplate the approaching car and strictly follow the order of the test sheets when making estimates and writing them down. After having written down their estimates they should lean back taking their original head position. The driver of the test car (B) would flash the headlights twice and then start the next trial. Subjects knew that car (B) would close at different speeds but were unaware of the fixed sequence of approaching speeds.

After reading the instructions, subjects were told how to adjust their seating position (as described in the apparatus and stimuli section) while the instructor supervised the adjustment. Subjects were told to lean their head against the headrest while contemplating the approaching car only moving their eyes towards the target mirror scene in order to keep their original head position. They were allowed to move freely while filling in the test sheet after each trail but were told to lean against the seat and headrest before each trail to keep their position constant.

Prior to the 8 experimental trials subject experienced two calibration trials in which they were asked to look at the approaching car through each of the mirrors (the order was randomised during the experiment). During the calibration trials the instructor drove the test car at 25 km/h. Subjects were unaware of the calibration speed but were told that it corresponded to a rating of 5 on the speed estimation scale.

After the calibration trials, subjects were informed about the beginning of the actual experiment and underwent 8 experimental trials. The driver tried to accelerate consistently and stop the test car at a similar point next to car (A) in each trial. Subjects watched the car from the very beginning of the acceleration phase but were aware of the starting line of the test track. After the trials the subjects were asked to fill in the questionnaire at the end of the test sheet and were subsequently rewarded with candy. Subjects were tested individually. Each session lasted about 45 minutes.

3.5 Analyses and calculation of parameters

The data was analysed with SPSS 16. Two separate multiple analyses of variance with repeated measures for dependent samples were conducted to measure the influence of the factors mirror type and speed on the two dependent variables acceleration estimates and confidence estimates. A t-test for dependent samples was used to compare differences in the means of confidence estimates between the two mirror types. Further analyses of variance included the between-subject factors speed sequence, mirror sequence, general mirror use in overtaking, mirror type considered most reliable in general, mirror type most convenient for estimates during the experiment, driver-side mirror type on the car most frequently used. The a priori significance level was .05.

4. Results

4.1 Descriptive statistics

Of the 19 participants who had a driver's licence 78.9% reported they used both, the centre rear view mirror and the driver side rear view mirror when considering a lane change manoeuvre, 10.5% reported to use only the middle mirror and another 10.5% used exclusively the driver side mirror. None of the participants reported not to be using any mirror at all (figure 2).

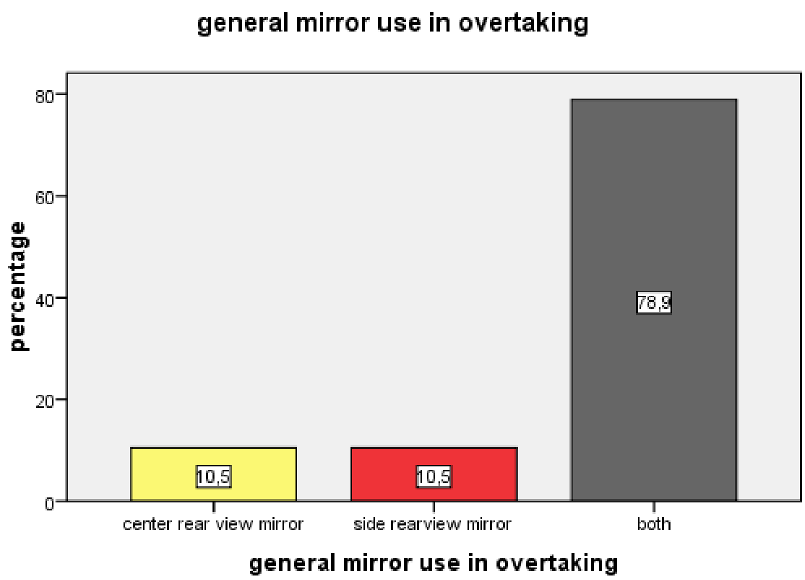

Figure 2. Participants' general use of centre rear view mirrors, side rear view mirrors or both mirror types when performing a lane change manoeuvre.

As for reliability of the two mirror types, 75% considered the centre mirror to be more reliable, 25 % preferred the driver side mirror (figure 3).

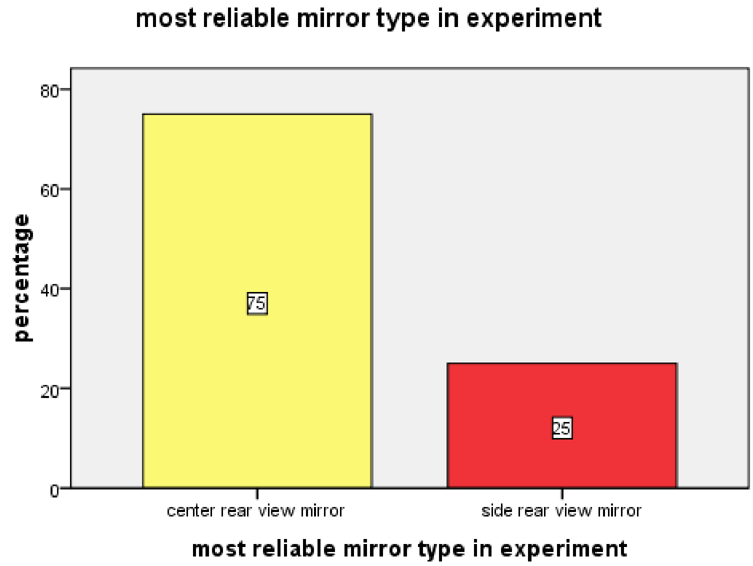

Figure 3. Participants' perception of general reliability of centre rear view mirrors and side rear view mirrors.

In the actual experiment 30% found the convex driver-side mirror more convenient, 45% the planar centre mirror and 25% found both mirror types equally convenient for their estimates (figure 4).

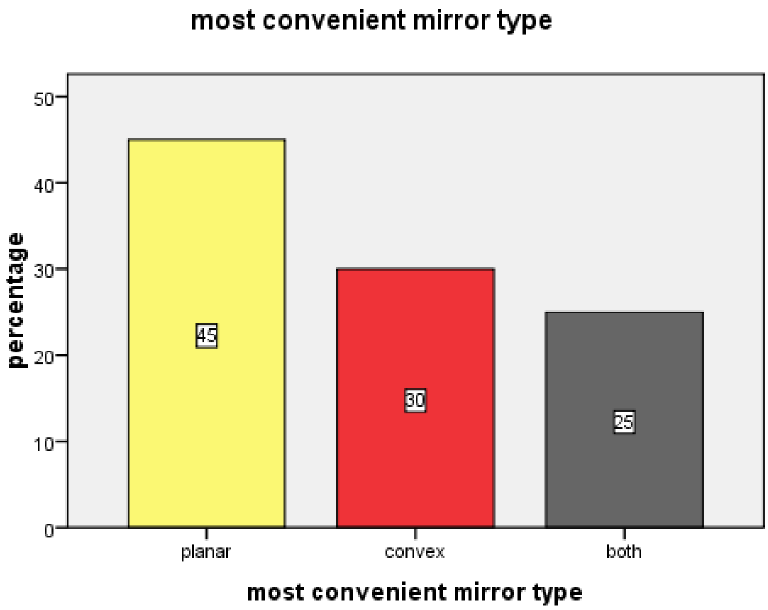

Figure 4. Participants' choice of the most convenient mirror type during the experiment.

In terms of experience with different types of driver-side mirrors, 55% reported to have an aspheric mirror on their most frequently used vehicle, 20% convex, 20% planar (figure 5).

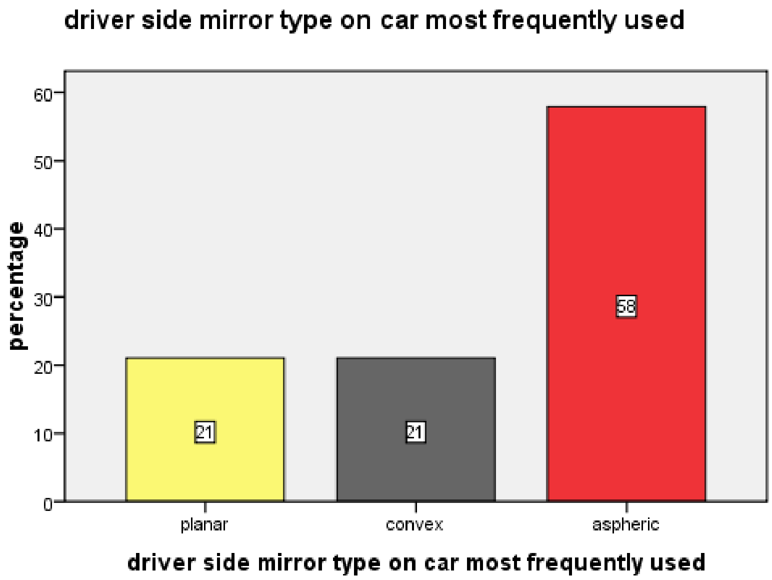

Figure 5. Driver side mirror type on the car most frequently used by participants.

4.2 Effects on acceleration estimates

Table 1 shows means and standard deviations of the 8 acceleration estimates. Figure 6 shows a comparison of acceleration estimate means for the two mirror types.

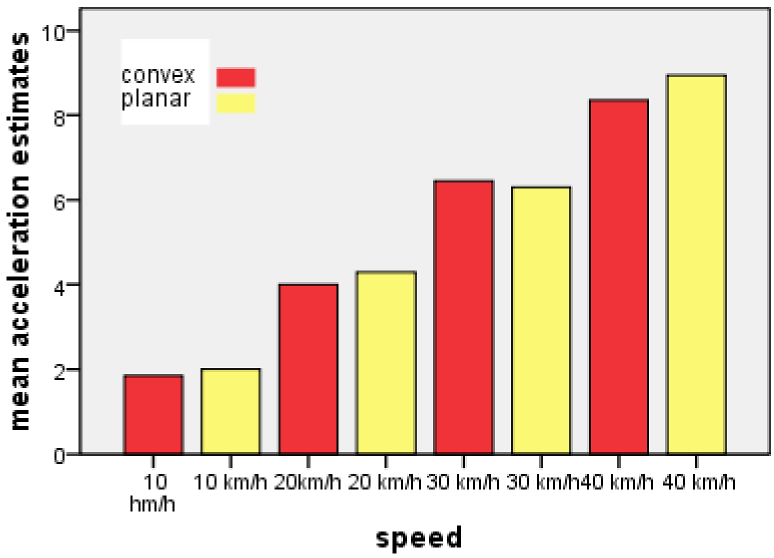

Figure 6. Mean acceleration estimates sorted by closing speeds in a direct comparison of the convex and the planar mirror.

No significant effect of mirror type on the acceleration estimates was found, *F*(1, 19) = 2.11, *p* =.163. Subjects' acceleration estimates were independent of whether they used the convex driver side mirror or the planar centre mirror. There was no significant interaction between mirror type and speed *F*(3,19) = 1.395 *p* = .253.

Table 1

Mean and standard deviations of acceleration estimates for different closing speeds and mirror types

	convex mirror		*planar mirror*	
speed (km/h)	*mean*	*sd*	*mean*	*sd*
10 km/h	1.85	.813	2.00	.858
20 km/h	4.00	1.124	4.30	1.380
30 km/h	6.45	1.395	6.30	1.418
40 km/h	8.35	.988	8.95	.945

However, speed of the closing car had a highly significant main effect on acceleration estimate, *F*(3, 19) = 319.388, *p* < .001. Post-hoc analyses with pairwise t-tests using bonferroni correction revealed a significant difference in acceleration estimates between all possible combinations of closing speeds: The 10 km/h trial estimates were smaller than the 20 km/h ($t(19) = -13.24$, $p < .001$), 30 km/h ($t(19) = -16.12$, $p < .001$) and 40 km/h trial estimates,($t(19) = -29.5$, $p < .001$). The 20 km/h estimates were smaller than the 30 km/h ($t(19) = -9.63$, $p < .001$) and the 40 km/h trial ($t(19) = -20.64$, $p < .001$) and the 30 km/h trial estimates were smaller than the 40 km/h trial estimates, ($t(19) = -9.52$, $p < .001$). This means that the task was properly carried out by the participants and that the acceleration measure had succeeded. Figure 7 shows mean acceleration estimates for the different closing speeds and mirror types suggesting that greater speeds were associated with greater acceleration estimates.

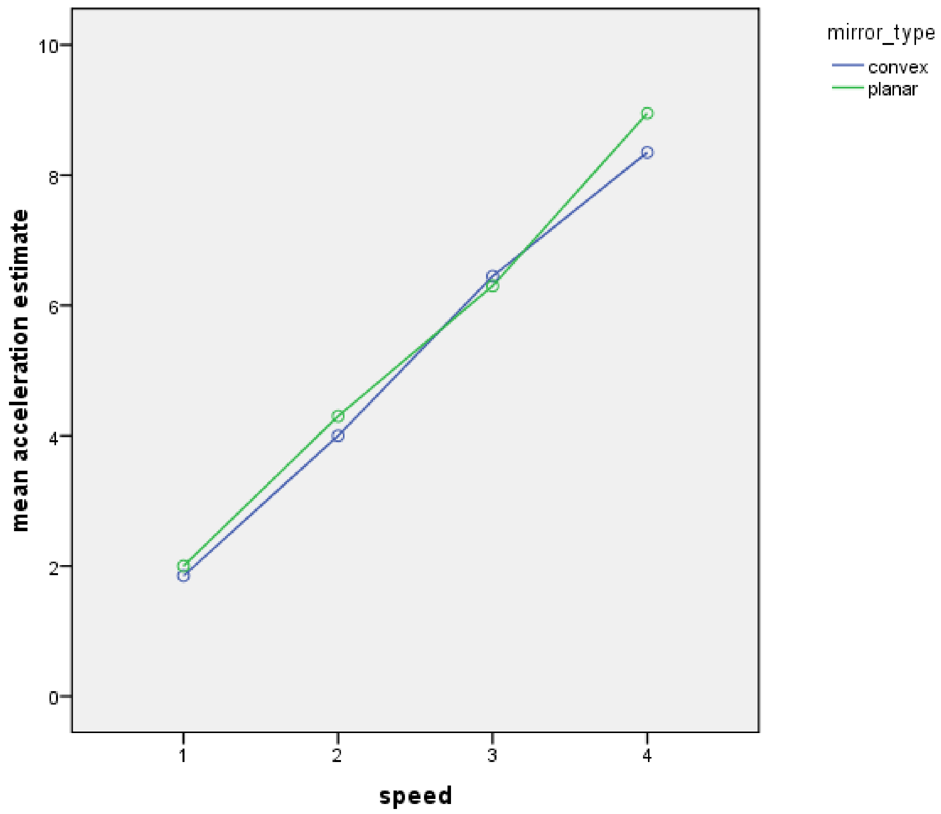

Figure 7. Main effect of speed on acceleration estimates.

In a further analyses of variance the between-subject factors mirror sequence and speed sequence were included but showed no significant main effect of mirror sequence ($F(1, 16)= .356$, $p=.559$, ns) or speed sequence ($F(1, 16) = .672$, $p= .424$, ns).

The average acceleration values reported above may not be a sensitive enough measure of potential differences between the planar and convex mirror because the real-world task produced rather large variability. A more sensitive method is to compare the acceleration values on an individual basis for each velocity. We tabulated for each observer which mirror type produced larger acceleration values at a given velocity. Here the results show rather clearly that larger accelerations were chosen more often with the planar mirror. A Chi-square test (χ^2 (6,n=20) = 13.593, $p < .05$) revealed a significant difference from an equal distribution. Thus, in a larger number of trials, observers accelerated less with the convex mirror as compared to the planar mirror. The number of trials with observers correctly solving the task by accelerating equally in the convex and planar mirror trials was less than 50 %. In 45 out of 80 trials mirror type led to a difference.

Table 2

A count of those cases where a given participant produced higher accelerations when viewing the approaching car through the planar vs. the convex rear view mirror on the driver's side. The fourth column is a count of the ties when both mirrors received equal acceleration values.

speed (km/h)	*planar +*	*convex +*	*planar= convex*	*sum*
10	5	3	12	20
20	9	4	7	20
30	7	6	7	20
40	9	2	9	20
sum	30	15	35	80

4.3 Effects on confidence estimates

An a priori t- test comparing the mean of confidence estimates for the planar and the convex mirror showed no differences, t(19)= -1.601, p= .126, n.s.. Table 3 shows means and standard deviations of confidence estimates for the different closing speeds and mirror types. Figure 8 shows a comparison of confidence estimates for different closing speeds and mirror types.

Table 3

Mean and standard deviations of confidence estimates for different closing speeds and mirror types

	convex mirror		*planar mirror*	
speed (km/h)	*mean*	*sd*	*mean*	*sd*
10 km/h	3.35	.671	3.1	.788
20 km/h	2.8	.768	2.55	.759
30 km/h	2.75	.716	2.75	.637
40 km/h	3.0	.858	2.85	.745

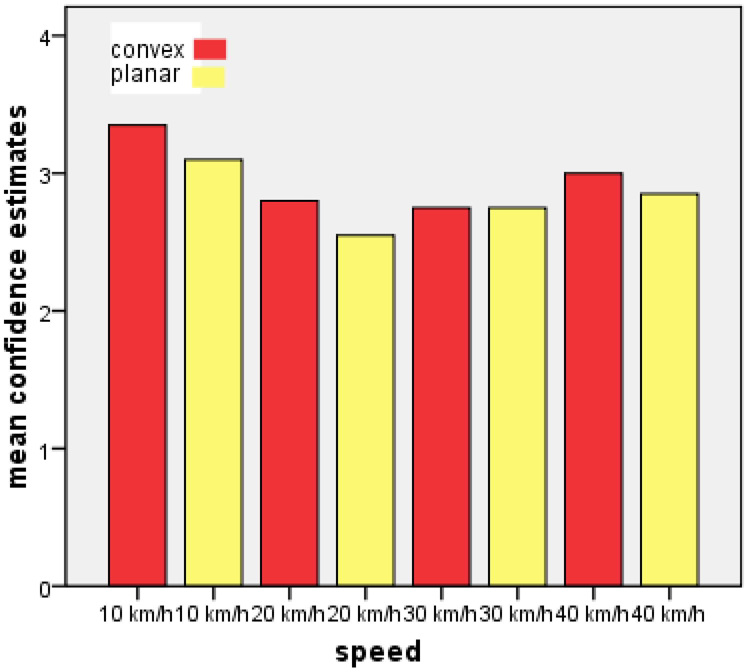

Figure 8. Mean confidence estimates sorted by closing speeds in a direct comparison of the convex and the planar mirror.

As in the case of acceleration estimates the mirror type did not have a significant effect on confidence estimates ($F(1,19) = 2.567$, $p = .126$, n.s.) nor did the interaction between mirror type and speed $F(3,19) = .523$ $p = .668$, n.s.). Subjects were similarly confident in their acceleration estimates no matter which of the two mirror types was used. On the contrary, speed was again a highly significant factor: $F\ (3,19) = 5.933$, $p < .001$ pointing to the conclusion that subjects weren't equally confident for each closing speed and that this pattern of insecurity is similar over the two mirror types. Post-hoc analyses with pairwise t-tests using bonferroni correction revealed a difference between the 10 and the 20 km/h trial (*t*(19) = 3.93, *p* = .005.), and the 10 and the 30 km/h trial (*t*(19) = 3.23, *p* = .027). Subjects' felt systematically less confident about their acceleration estimates in the 20km/h and the 30km/h trial. Figure 9 shows mean confidence estimates by closing speed.

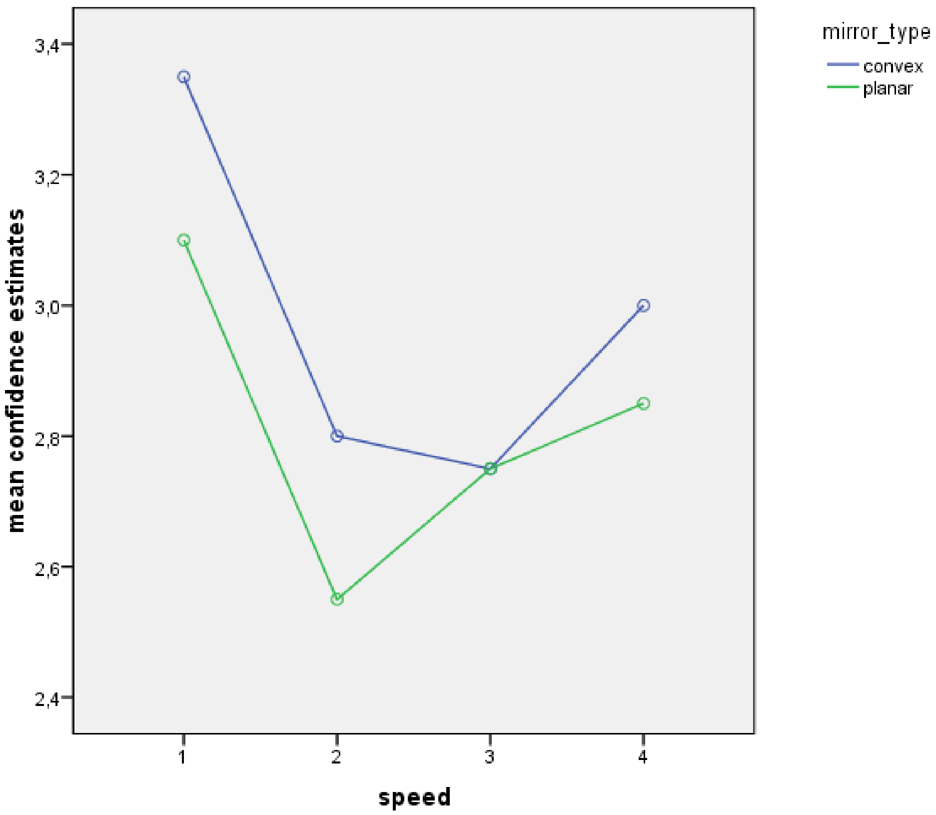

Figure 9. Main effect of speed on confidence estimates.

Further analyses including the factors speed and mirror sequence revealed no significant main or interaction effects on confidence estimates (*F*(1, 16)=.748, *p*=.4, n.s. and (*F*(1,16)= .561, *p*= .465, n.s. respectively.

5. Discussion

Most of the previous research points to the fact that curvature has an effect on measures associated with perceived speed, smaller radii often being associated with larger time-to-contact and distance estimates (e.g. Fisher & Galer, 1984; Hecht & Brauer, 2007; Flannagan et al. 1996). These mostly artificial stimulus environments are not found with equal strength in our real-world scenario. Averaged data did not reveal any systematic effects of mirror radius on acceleration estimates. The average acceleration estimates were independent of mirror type, sequence of presented closing speeds or sequence of mirror types used. As to be expected, acceleration estimates were strongly dependent on the speed of the approaching car: Larger closing speeds were associated with larger acceleration estimates. In fact within one mirror type and between trials, each acceleration estimate was significantly different from the other. This pattern was found for both mirror types.

When looking at the data on an individual basis, however, a superiority of the planar mirror was found. In roughly one half of the judgements, it made no difference for observers which mirror they were using. Acceleration estimates were equal with the driver-side mirror and the planar center mirror. Looking at the other half of the judgements, however, a majority of our participants produced safer, that is larger accelerations with the planar mirror.

The results of the confidence estimates point to the fact that some speed trails may have been more distinctive or recognizable than others: While confidence estimates were again independent of mirror type and speed- or mirror sequence, closing speed proved to be the only significant factor influencing the estimates: Subjects weren’t equally confident for each closing speed inasmuch as their confidence in acceleration estimates was systematically larger in the 10 km/h trial than in the 20 km/h and 30 km/h trial. The fact that this pattern of insecurity is similar for the two mirror types indicates that some closing speeds must have been more distinctive than others or may have been used as anchors for the estimates.

The resolution of perceptual ability in our study was limited compared to the preceding laboratory studies. The latter allow for estimates that are much more stable and precise, be it time-to-contact judgements or judgements of LMPS as measured in the experiments by Fisher & Galer (1984), Hecht & Brauer (2007) or Flannagan et al. (1996). The latter are measures that require a prediction of an upcoming event on the basis of a perceptual impression while in our study the relevant information for estimates of required acceleration could be retrieved directly from the perceptual impression i.e. watching the car approach on the test track.

Thus, our study should be seen as an attempt to validate the laboratory findings which indicate that nonplanar mirrors compromise time-to-contact judgments on the dangerous side. The validation failed when considering large average effects. However, our data suggest that for about half our participants judgments were compromised and accelerations were smaller when the convex mirror was used.

Given the necessary limitations of the real-world study we take our results to support the notion that convex mirrors produce time-to-contact estimates that may be too long. Among the limitations are the indirect judgments and the fact that visual angle was not held constant.

6. References

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Appendix

A: Pictures

Figure 10. The view through the convex driver side mirror showing the test car B at the starting position, the beginning of the test track, and the end of the test track.

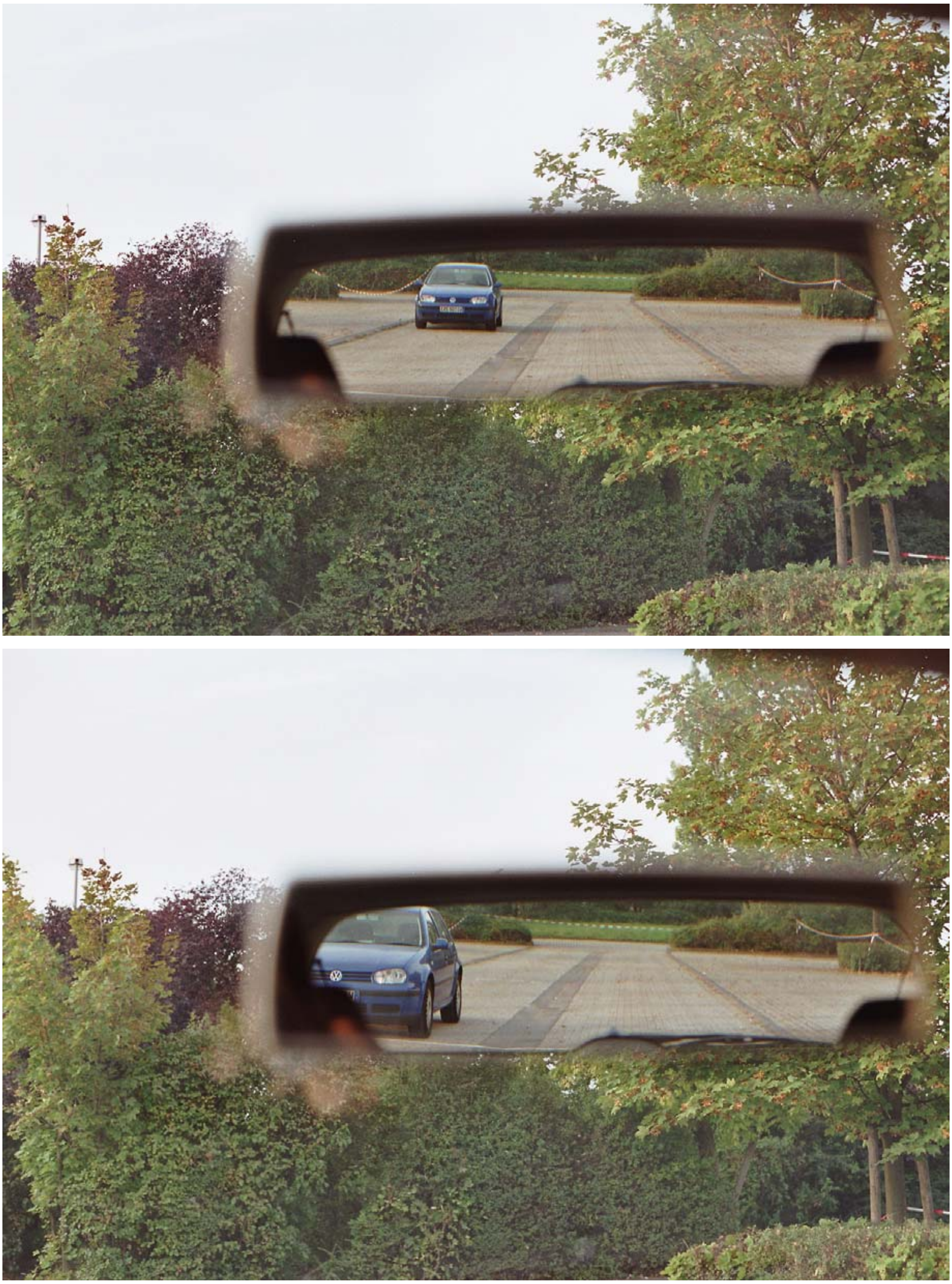

Figure 11. The view through the planar centre mirror showing the test car B at the starting position, the beginning of the test track, and the end of the test track.

B: Testsheet version A and B