INDIVIDUAL CHARACTERISTICS AFFECTING INTERSECTION BEHAVIOR IN A DRIVING SIMULATOR

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Abstract

Virtual instructors are developed to be used in training simulators. For effective feedback, however, the aspects that affect performance should be known. Performance-data was analyzed for 24 participants in an intersection encounter task in a driving simulator. Results show that large differences exist between participant's driving behaviors. Factor analysis revealed four common factors (explaining 70.7% of the variance), which represent individual characteristics: safety-motives (F1), skills (F2), encounter strategy (F3), and 'longitudinal recklessness' (F4). F1 and F2 negatively correlate. Older participants had higher F1-scores, but lower F2-scores. Collision-involvement related to high F4-scores. The results indicate that motives should be taken into account when assessing a driver in a simulator and that the use of personal factor-scores has the potential to improve adaptive simulation-based driver training.

Keywords: Driving simulators, driver assessment

1 Introduction

Simulators are a promising means for driver training. Currently, approximately 100 Dutch driving schools are using a low-cost driving simulator for initial driver training. Simulators provide many advantages over real cars, such as purpose-developed virtual environments, and objective performance assessment. Furthermore, instructions and feedback on performance can be given directly by the simulator to enable adaptive training without the intervention of a human instructor [1] [2] [3]. The virtual driving instructor should be able to assess the strengths and the weaknesses of the student in the simulator [4]. More knowledge is needed to judge which aspects have to be taken into account to assess a simulator driver [5]. Literature concerning real car driving reports that a good driver cannot be solely characterized as someone who is competent in executing tasks (e.g. [6]). Intentional aspects, such as safety-motives, should also be taken into account when explaining driver behavior [7]. This distinction between driver competency on the one hand and driver motives on the other hand seems analogous to the distinction between errors and violations [8] [9], driver performance and driver behavior [10], and driving skills and driver style [11]. Earlier research demonstrated that motivational aspects, such as intentional violations and speed-choice, also play a role in explaining simulation-based driving [4] [5] .
Several researchers have described a relationship between (higher-level) motives and (lower-level) skills by means of functional hierarchies (e.g., [12] [13] [14] [15]), or by means of motivational models where

speed-control plays a central role (e.g. [16]). In these frameworks, lower-level skills are used to satisfy higher-order goals, so that more skilled drivers adopt higher speeds for example (e.g. [6]).
This paper aims to provide a deeper understanding of the aspects that have to be taken into account when assessing a driver in a simulator. Therefore, participants had to drive a route that included unsignalized intersections where they encountered another vehicle. A factor analysis was performed to identify the latent structure amongst variables.

2 Method

2.1 Apparatus

Two 'Dutch Driving Simulators' (Fig. 1) were used in the experiment reported here. The simulators were connected in a way that allowed the drivers of both simulators to encounter each other in the same virtual world. The simulators were provided with all normal controls (steering wheel, accelerator, brake). Force feedback was provided on the steering wheel according to the self-aligning torque of the front wheels. Longitudinal motion cueing was provided through vibration elements in the steering wheel and the driver's seat. The front view projection had a resolution of 1024x786 pixels; the side-views featured resolutions of 800x600 pixels. The dashboard, the vehicle interior and mirrors were integrated in the projected image. Auditory information was provided through headphones.

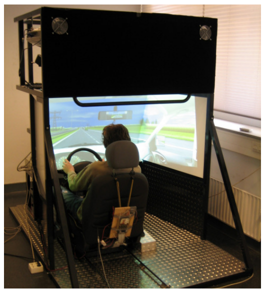


Fig. 1. One of the driving simulators that was used in the experiment

2.2 Experiment design and procedure

At first, to get used to the simulator, participants completed a six-minute practice session, which took place in the same virtual environment as the actual experiment, but in reverse direction. Next, two sessions had to be completed that each consisted of a 32-kilometer route (Fig. 2), that included 40 unsignalized four-way intersections. On average, participants took 42 minutes to complete a session. Participants had a small break in between sessions.
At 32 of the 40 intersections, participants (vehicle A) encountered another vehicle (vehicle B). During one of the two sessions, an automatic controller ensured that vehicle B reached the intersection at the same moment the participant did (session C). During the other session, vehicle B was controlled by a human experimenter (session H). Session C and H were presented in randomized order. The effects of session type (C or H) on driving behavior are not considered in this article.
Vehicle B could either approach from the right (situation-types 1 and 4) or from the left (situation-types 2 and 3). In the Netherlands, the driver approaching from the right has right of way and the participant should yield. During situation-types 3 and 4, vehicle B acted unexpectedly by maintaining speed or slowing down respectively. Duration situation-type 5, no vehicle approached. More information concerning the situation-types can found in Table 1 and Fig. 2.

Table 1. Overview of situation-types

Situation-type	Occasions per session	B approached from	B behavior
1	12	Right	Maintained speed (expected)
2	12	Left	Slowed down (expected)
3	4	Left	Maintained speed (unexpected)
4	4	Right	Slowed down (unexpected)
5	8	-	-

Intersections were 30m by 30m wide and lane widths were 5m. Buildings were placed close to the sidewalk so that vehicle B could first be perceived by when vehicle A was, on average, 31 meters before the centre of the intersection. The effects of visibility on driving behavior are not addressed in this article. Intersections were connected by straight road stretches of 600m. Ten curves were included in the route to create a more realistic driving task. Behavior through these turns was not included in the data analysis. Participants could encounter oncoming road users on the road stretches between intersections. In case of a collision, participants are placed a while back along the route. In such instances, they were instructed to turn the ignition key and continue their session. During the entire experiment, the simulator was used in automatic gear shift mode.

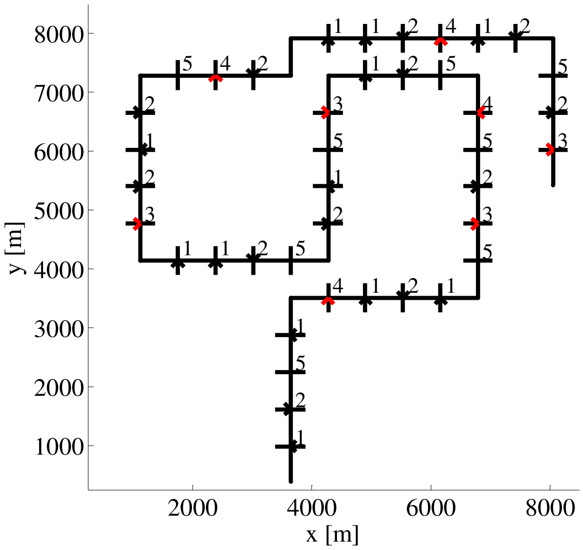


Fig. 2. Top view of the route. The arrows indicate the direction from which vehicle B approached the intersection. Red arrows indicate unexpected behavior of vehicle B. Numbers at intersections are explained in Table 1.

Table 2. Dependent measures calculated for each intersection encounter

Safety-related measures	**Unit**	**Description**
TTC_min	s	Minimum time to collision for (possible) collision course between A and B (e.g. [17], [18]). When A and B were never on a collision course, TTC_min was set at infinite.
PET	s	'Post Encroachment Time': time difference between arrival of A and B at each other's lane centres (e.g. [19] [17])
TTC_diff25	s	Difference between Time To Collision Point of A and B when Distance to Collision Point of A is 25m (see Appendix A)
Speed-related measures		
Speed_mean	km/h	Mean speed
Speed_min	km/h	Minimum speed
Speed_max	km/h	Maximum speed
Speed_IC+15	km/h	Speed when 15m past the intersection centre (leaving intersection)
Tactical behavior		
Yielding	0 or 1	0 if A crossed the intersection centre first, 1 if B crossed the intersection first
Vehicle-control-related measures		
Throttle_max	%	Maximum throttle position (0% is released, 100% is fully applied)
Brake_max	%	Maximum brake position (0% is released, 100% is fully applied)
Braking_time	s	Duration that the brake was applied (deeper than 0%)
Time_hard_braking	s	Duration that the brake was applied deeper than 60%
Time_throttle_released	s	Duration that the throttle was released
DTIC_throttle_release	m	Distance to intersection centre when throttle was first released
DTIC_brake	m	Distance to intersection centre when brake was first depressed
Time_standing_still	s	Duration spent standing still
Throttle_IC+15	%	Throttle position 15m past the intersection centre (leaving intersection)
Skill-related measures (longitudinal and lateral tracking performance)		
SD_LP	m	Standard deviation of lateral position during 10s interval on straight stretches before encounter
SD_Speed	km/h	Standard deviation of vehicle speed during 10s interval on straight stretches before encounter
Effort-related measures		
Throttle_release_events	#	Number of times the throttle was released (for event-based approach for calculating effort (e.g. [21], [22])
Brake_events	#	Number of times the brake was depressed
SD_Steer	deg	Standard deviation of the steering wheel angle during 10s interval before intersection
SD_Throttle	%	Standard deviation of throttle position during 10s interval before intersection ([23]).

Note that the classification of the dependent measures is based on indications from literature. The distinctions do not necessarily have to be clear cut. In the next sections, the measures will be clustered by means of factor analysis.

2.3 Participants and instructions to participants

Twenty-seven participants were obtained from the SWOV Institute for Road Safety Research database. Participants were paid € 20. Three participants experienced symptoms of simulator sickness during the training session and therefore decided not to participate in the experiment, so 24 participants (12 males, 12 females) participated. The participant's mean age and mean duration of driver's license possession were 48.8 (SD 13.7) years and 27.4 (SD 13.3) years respectively. Five of the 24 participants did not complete both sessions because of simulator sickness, but their results were included in the data analysis. Additionally, due to simulator software artifacts, data of 13 intersection encounters have not been obtained. In total, data of 1676 encounters were obtained.

Participants were presented with a leaflet which instructed them to drive as they would normally drive in a similar real-life situation. Participants were explicitly instructed to keep to the speed limit of 50 km/h, and to drive straight on at intersections. Participants were only informed of the distinction between session C and H after completing the experiment.

2.4 Dependent measures

Table 2 shows the dependent measures used in this study. The measures relate to the participant's (vehicle A) behavior during an intersection encounter. Intersection encounters are defined as the period that vehicle A is between 150m before and 50m past the intersection centre.

3 Results

3.1 Participant means

To determine behavioral differences between participants, the means for each dependent measure were calculated for every participant (called participant means). Table 3 shows the means, standard deviations, minima, and maxima of the participant means. The table shows large inter-personal differences. For example, the 'minimum participant' had a much lower mean minimum speed (M = 4.4 km/h) than the 'maximum participant' (M = 33.5 km/h). Looking at yielding, the minimum participant yielded to the other vehicle 37.5% of the times, while the maximum participant yielded 52.6% of the times. The inter-personal variability seems to be even larger when examining driving behavior within a particular situation-type. For example, during situation-type 4, two participants always yielded, while four participants never yielded. To summarize, as remarkable differences in driving behavior between participants were evident, it indeed seems worthwhile to unveil the underlying causes.

Table 3. Mean, standard deviation, minimum and maximum of participants means (N=24) for each dependent measures.

Measure	Mean	SD	Minimum	Maximum
TTC_min [s] *	3.80	0.63	2.98	5.54
PET [s]	3.00	1.03	1.92	7.03
TTC_diff25 [s] *	1.36	0.73	0.41	3.36
Speed_mean [km/h]	40.66	3.90	28.86	46.79
Speed_min [km/h]	22.35	7.08	4.42	33.48
Speed_max [km/h]	53.38	1.34	51.49	56.41
Speed_IC+15 [km/h]	42.91	3.21	33.58	50.11
Yielding [%]	42.98	3.33	37.50	52.63
Throttle_max [%]	47.12	14.43	25.90	99.16
Brake_max [%]	28.97	10.08	16.91	51.14
Braking_time [s]	2.14	1.07	0.49	5.83
Time_hard_braking [s]	0.12	0.09	0.00	0.35
Time_throttle_released [s]	8.65	2.68	4.19	15.88
DTIC_throttle_released [m]	90.65	11.61	60.23	110.50
DTIC_brake [m]	46.31	10.47	24.29	64.48
Time_standing_still [s]	0.19	0.19	0.000	0.59
Throttle_IC_+15m [%]	17.68	7.78	4.44	35.35
SD_LP [m]	1.34	0.13	1.08	1.58
SD_Speed [km/h]	1.33	0.40	0.66	2.14
Throttle_release_events [#]	2.29	0.69	1.35	3.54
Brake_events [#]	1.08	0.38	0.36	2.20
SD_Steer [deg]	1.21	0.25	0.95	1.90
SD_Throttle [%]	4.19	1.74	1.66	7.72

** The participant medians are listed instead of the participant's means because of the highly asymmetric distribution*

3.2 Factor analysis

The previous section demonstrated that participants differed greatly in driving behavior. Common factors can explain much of the variance between participants, because the measures feature many relationships. For example, participants who had a high mean speed, tended to yield to vehicle B less frequently. A Spearman correlation coefficient supported this observation ($r(24) = -.48$, $p=.018$). Note that in this case, a causal relationship might exist because yielding is likely to reduce the mean speed of the intersection encounter. However, individual characteristics played a role as well in explaining variance, because correlations were also observed between independent encounters. For example, participants who had a high mean speed during situation-type 5, tended to yield significantly less often during situation-type 4 ($r(24) = -.58$, $p=.003$), and had a high mean speed during situation-type 2 ($r(24) = .93$, $p<.001$). Here, the correlations can be explained by individual characteristics, such as the participant's tendency to drive safely.

In order to reveal common factors that affected driving behavior, a Spearman 23x23 correlation matrix of the dependent measures was calculated. Factor analysis is a statistical technique that uses the correlation matrix to classify measures according to underlying (unobserved) factors. Using a so-called Scree Test on the eigenvalues of the correlation matrix, four factors could be identified which accounted for 70.7% of the total variance. The correlation matrix was submitted to an unweighted least squares factor analysis with Promax oblique rotation. We have opted for an oblique rotation because we expected that motives and skills correlate with each other. The pattern matrix and the structure matrix are shown in Table 4.

Careful observation of both the pattern matrix and structure matrix clarified that factor 1 (F1), accounting for 34.8% of the variance, can be best described as safety-motives. The defining items are generally related to slow, safe, and careful driving. High pattern-coefficients (>0.4) on F1 are found for the safety-related measures, Braking_time, Brake_events, DTIC_brake, Yielding, and Brake_max measures. Low F1-coefficients (<0.4) were related to Speed_min, Speed_mean, and Time_hard_braking. So, participants with high F1-scores had fewer or smaller conflicts with vehicle B, released the throttle and brake at larger distances before the intersection, and tended to let vehicle B cross the intersection first. They also drove with lower average speeds, lower minimum speeds, but not convincingly with lower maximum speeds.

Factor 2 (F2), accounting for 13.9% of the variance, can be best characterized as skills. High coefficients are found for Braking_time, and Throttle_IC_+15 measures, while low coefficients are found the skill-related and effort-related measures, as well as for Time_throttle_released and DTIC_throttle_released. Note that literature also describes a positive correlation between SD_LP and driver effort [24]. So, skilled participants had better longitudinal and lateral tracking performance, lower-effort scores, in terms of throttle and steering wheel activity in between the intersections, as well as in terms of throttle-released-events during the intersection encounters. The structure matrix reveals that skilled participants adopted higher speeds and vice versa. Generally, skilled participants adopted higher speeds and first released the throttle at smaller distances to the intersections.

Factor 3 (F3), accounting for 13.3% of the variance, can be characterized as the encounter strategy. High coefficients are obtained for Speed_IC+15, Throttle_max, Throttle_release_events, and SD_Throttle. A low coefficient is found for Time_standing_still. Participants with high F3-scores were more active with the throttle, approached the intersection with a normal speed and left the intersection with higher speeds; a strategy which we will refer to as 'flying'. Its counterpart can be described as a 'wait and see'-strategy, which is often accompanied by standing still. Note that F3 does not explicitly relate to yielding behavior.

Factor 4 (F4), accounting for 8.6% of the variance, we will refer to as 'longitudinal recklessness'. High F4-coefficients are found for Brake_max, Speed_max, and Time_hard_braking, while a low coefficient is found for DTIC_brake. Summarizing, participants who scored high on F4 drove with higher maximum speeds, and braked later and harder.

In order to obtain more insight into the four different factors, a factor-score was calculated for each participant according to the Bartlett weighted least squares method. Factor-scores were standardized so that the transformed scores have a mean of zero and a standard deviation of one. For each factor, the participant with the highest factor score and the participant with the lowest factor score were selected. Fig. 3a to 3h show the individual speed versus distance profiles of these participants for situation-type 2, session C and situation-type 4, session H. Situation-type 2C concerns computer-controlled vehicle B approaching from the left and (expectedly) slowing down, while situation-type 4 concerns a human-controlled vehicle B approaching from the right and (unexpectedly) slowing down. These situation-types were chosen since they are relatively dissimilar.

Table 4. Pattern matrix, structure matrix, and communalities (Comm.) *. Cell colors correspond to the magnitude of the number. Measures are sorted in descending order according to the F1 coefficients.

	Pattern Matrix				Structure Matrix				
Measure	**F1**	**F2**	**F3**	**F4**	**F1**	**F2**	**F3**	**F4**	**Comm.**
Braking_time	1.07	0.45	-0.11	0.09	0.84	-0.03	-0.25	-0.12	0.899
Brake_events	0.90	0.10	0.13	0.19	0.78	-0.29	0.04	-0.04	0.674
DTIC_brake	0.80	0.22	0.16	-0.41	0.80	-0.29	-0.01	-0.56	0.802
Yielding	0.76	0.20	-0.03	0.01	0.66	-0.16	-0.13	-0.16	0.471
TTC_diff	0.64	-0.37	0.17	-0.17	0.85	-0.73	0.08	-0.45	0.904
TTC_min	0.55	-0.47	0.11	-0.08	0.78	-0.76	0.05	-0.36	0.820
PET	0.49	-0.39	-0.38	0.09	0.70	-0.58	-0.41	-0.23	0.700
Brake_max	0.42	-0.02	0.26	0.89	0.13	0.03	0.33	0.79	0.843
Time_throttle_released	0.30	-0.72	0.01	-0.10	0.68	-0.89	-0.01	-0.40	0.885
Time_standing_still	0.24	0.39	-0.56	0.11	0.09	0.34	-0.59	0.07	0.489
Throttle_max	0.19	0.13	0.84	0.30	-0.07	0.09	0.86	0.40	0.843
Throttle_release_events	0.12	-0.37	0.60	0.13	0.18	-0.42	0.62	0.07	0.559
DTIC_throttle_release	0.11	-0.64	0.15	-0.31	0.50	-0.79	0.12	-0.51	0.746
Throttle_IC_+15m	0.09	0.60	-0.01	0.26	-0.28	0.64	-0.01	0.41	0.469
SD_Throttle	0.00	-0.64	0.44	0.20	0.18	-0.60	0.50	0.08	0.614
Speed_max	-0.06	0.25	0.24	0.49	-0.36	0.42	0.30	0.62	0.503
SD_Speed	-0.08	-0.75	0.11	0.06	0.25	-0.70	0.16	-0.12	0.521
SD_LP	-0.22	-0.75	-0.18	0.08	0.14	-0.62	-0.11	-0.10	0.446
Speed_IC_+15m	-0.23	0.14	0.90	0.02	-0.41	0.21	0.92	0.25	0.958
SD_Steer	-0.36	-0.76	0.03	0.18	-0.05	-0.54	0.14	0.08	0.446
Time_hard_braking	-0.57	-0.27	-0.10	0.59	-0.61	0.18	0.07	0.67	0.692
Speed_mean	-0.62	0.39	0.27	0.13	-0.89	0.71	0.35	0.47	0.989
Speed_min	-0.93	0.17	0.15	-0.38	-0.92	0.50	0.21	-0.03	0.982

* The pattern matrix contains regression coefficients representing the measure's unique contribution to the factor's variance. The structure matrix contains correlations between the measure and factor's variance, taking into account factor-to-factor correlation. Communalities represent the proportion of the measure's variance which is accounted for by the four common factors.

Fig. 3a and 3b show that the maximum participant concerning F1 (safety-motives) was relatively slow, started braking early, braked for a long period of time, and did not brake hard. The minimum participant had a high average speed. Fig. 3c and 3d indicate that, concerning F2 (skills), the maximum participant appears to have good speed-tracking performance. The maximum participant released the throttle late and for short periods of time. The minimum participant had poor speed-tracking performance (did not drive at a constant speed before the intersection) and was relatively slow. Concerning F3 (Fig. 3e and 3f, encounter strategy), the maximum participant left the intersection with high speeds, and had many throttle release events, as can be seen from the irregular speed pattern when entering the intersection. The minimum participant left the intersection with low speeds. Concerning F4 (Fig. 3g and 3h, longitudinal recklessness), the maximum participant released the throttle late, braked late and hard, and had a high maximum speed. These behaviors seem to correspond with the skilled participant; however, it seems that the maximum participant did not have the speed-tracking capabilities of a skilled participant. The minimum participant did not show much longitudinal activity since the throttle was released the throttle early, and the brake was not depressed.

The individual characteristics can be recognized during two different independent situation-types. For example, the participant with the highest F3-score left the intersection with relative high speeds both during situation-types 2C and 4H. In other words, these characteristics were found independent of the situation-type, and can therefore be interpreted as an individual characteristic. Fig. 3 also demonstrates that participants can be very consistent. For example, the maximum F1-participant during situation-type 2C (see Fig. 3a) had very similar speed-profiles for all realizations. As mentioned, relatively large differences existed between participants. Again looking at Fig. 3a, it can be seen that the maximum participant always tended to almost come to a standstill while the minimum participant hardly decreased speed.

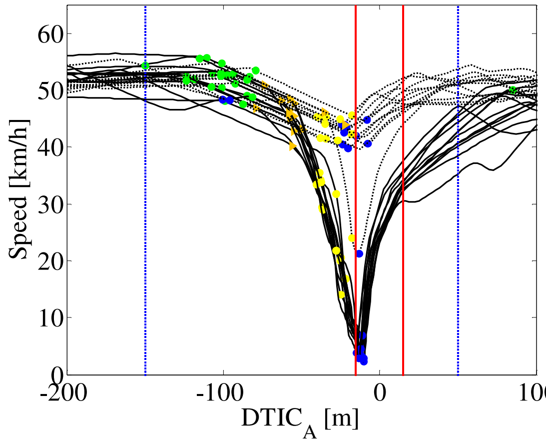


Fig. 3a. Factor 1, situation-type 2C

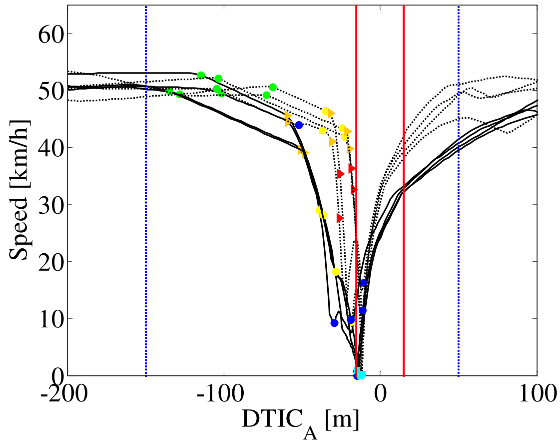


Fig. 3b. Factor 1, situation-type 4H

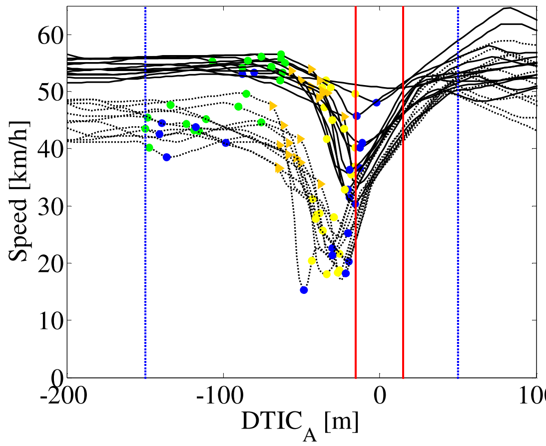


Fig. 3c. Factor 2, situation-type 2C

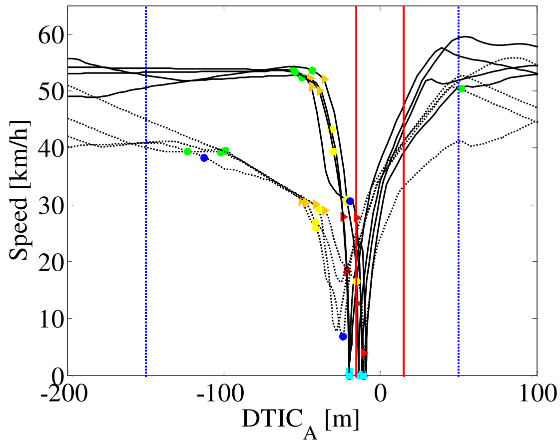


Fig. 3d. Factor 2, situation-type 4H

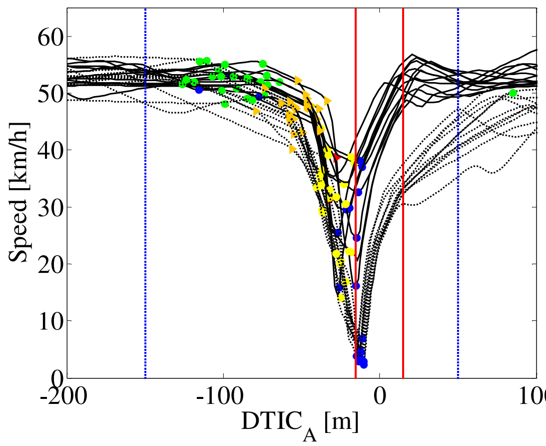


Fig. 3e. Factor 3, situation-type 2C

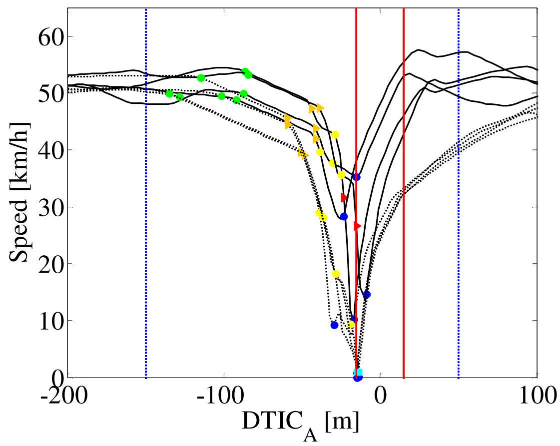


Fig. 3f. Factor 3, situation-type 4H

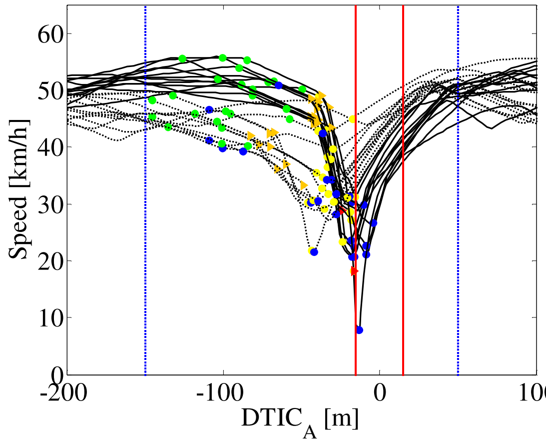


Fig. 3g. Factor 4, situation-type 2C

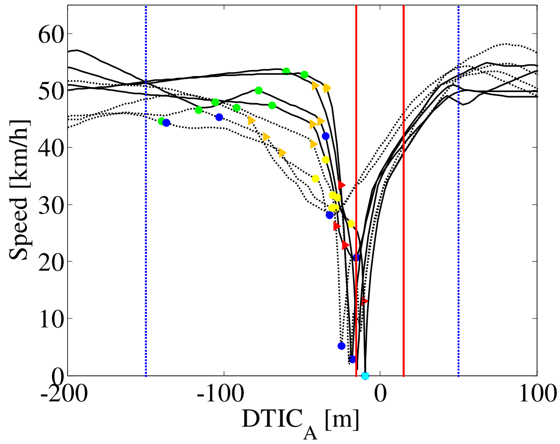
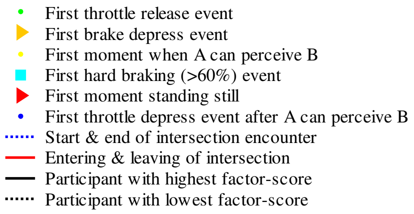


Fig. 3h. Factor 4, situation-type 4H

Fig. 3. Speed versus distance to intersection centre ($DTIC_A$) plots containing all realizations of the participant with the maximum factor-score (P14, P22, P3, and P1 respectively) and the minimum factor-score (P16, P15, P14, and P19 respectively), for factor 1 to 4, and for situation-types 2C and 4H. During situation-type 2C, a computer-controlled car approached from the left and stopped. During situation-type 4H, a human-controlled car approached from the right and slowed down.

Legend



The results above suggest that some factor-scores are related. Table 5 shows the factor correlation matrix. A moderate correlation is identified between F1 and F2. In other words, skilled participants had poorer safety-motives. This relationship is illustrated in Fig. 4. These results are in line with earlier research findings concerning (simulation-based) driving in that skilled drivers adopt higher speeds (e.g. [5]).

Table 5. Factor correlation matrix

	F1	F2	F3
F2	-.479		
F3	-.126	-.047	
F4	-.302	.292	.142

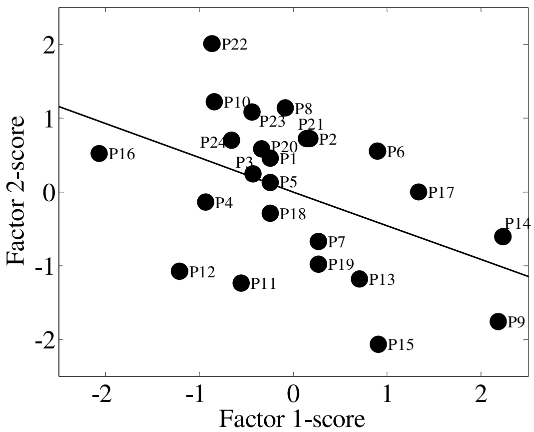


Fig. 4. Factor 2-score versus factor 1-score for all participants. The solid line represents a linear fit.

3.3 Factor-score predictors

As indicated above, factor-scores can be interpreted as individual characteristics. Not surprisingly, the factor-scores correlate with other personal characteristics, such as age. An interesting relationship was found between participant's age and the F1 and F2-scores. Age significantly correlated with F1-score (r(24)=.548, p=.006), which indicates that older participants adopted a safer driving style. Age negatively correlated with F2-score (r(24)=-.700, p<.001) which indicates that older participants had poorer skills. These results are in line with literature which reports that older drivers drive with lower speeds and commit fewer violations, but suffer more skill-based errors and have poorer lane-keeping performance than younger drivers (e.g. [9], [25])

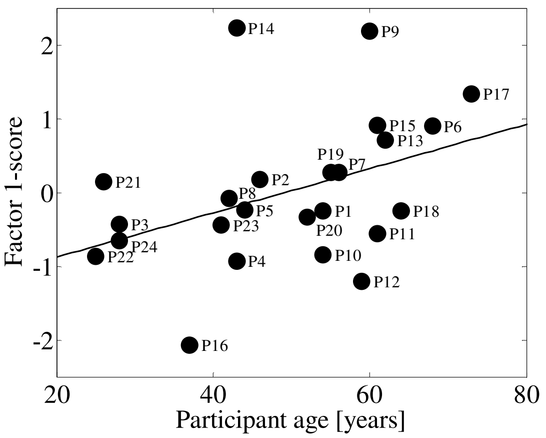


Fig. 5. Factor 1-score versus the age of the participant. The solid line represents a linear fit.

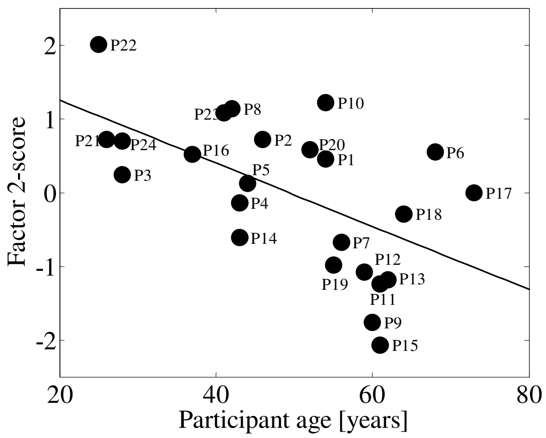


Fig. 6. Factor 2-score versus the age of the participant. The solid line represents a linear fit.

Finally, an attempt is made to identify collision-liable participants. For this purpose, the mean factor-scores were calculated of four participants who were involved in a collision, and twenty participants who were not involved in a collision (Table 6). Interestingly, collision-free participants can be characterized as having significantly lower F4-scores and not as having significantly lower F1-scores. Apparently, in the simulated environment, being reckless is worse than being quick and unsafe according to the safety-related measures.

Table 6. Means and standard deviations of factor-scores of participants according to their involvement in a virtual collision.

	F1	F2	F3	F4
Mean score of participants who were involved in a collision (P1, P8, P13, P22)	-.122	.602	.233	1.070
Mean score of twenty participants without collisions	.245	-.120	-.046	-.214
Significance (Wilcoxon test)	.908	.296	.561	.040

4 Discussion

This study showed that large differences exist between individuals on a driving simulator. It was demonstrated that variance in simulation-based car driving behavior can only partially be explained by 'skills'. However, when looking at the current standard of simulation-based training, the main focus is on acquiring vehicle handling skills and reducing driving errors. A typical example of skill-training is a scenario during which the student has to react adequately to a moose walking onto the middle of the road [26]. These tasks emphasize vehicle handling skills and reaction times. Our belief is that, in order for the student's behavior to better comply with the norms, more emphasis should be on influencing motives, creating knowledge of traffic rules, and safety-awareness, instead of training of lower-level skills. The disadvantage of exclusive training on skill-aspects of the driving task is supported by fidelity-issues: since simulators never provide an exact copy of reality, one can question the benefits of training vehicle control. We also found that skilled drivers adopted higher speeds, which is in line with theories such as motivational models and hierarchical structures [6]. Perhaps, this can be interpreted as that drivers apply their skills (or effort) to drive faster. If so, the significance of assessing drivers on motivational aspects such as safety-motives becomes even greater.

Since participants differed, it seems useful to attribute factor-scores to individuals. For example, a score for safety-motives can be calculated, and the training program can be adapted according to this score.

Quantification of individual characteristics seems useful also for Advanced Driver Assistance Systems (ADAS). Personal driver-profiles can be used to adapt ADAS to the personal needs and whishes of each individual driver [27] [28].

The first two factors that were identified during simulation-based driving coincided with common factors researchers identified concerning real car driving (e.g. [7]). Apparently, (speed-related) safety-motives play a role in the simulator, and quantifying safety deserves attention. This study used three safety-related measures. One of the disadvantages of the existing TTC_min measure is that when A and B are not on collision course, TTC_min cannot be determined [18]. The percentage of intersection encounters for which TTC_min could not be determined was highly dependent on situation-type (for example, 76% during situation-type 2, and 1.8% during situation-type 4), which is in accordance with literature [17]. In cases where no TTC_min could be determined, dangerous conflicts could still occur, for example when A and B just missed each other at high speeds. Therefore, TTC_min should be used concurrently with PET [17]. The newly created TTC_diff25 measure yielded a high communality and could discriminate collisions 25m before the estimated collision point (see Appendix A). Therefore TTC_diff could be a good alternative for the TTC_min and PET measures.

Interestingly, no significant relationship between low F1-scores (poor safety-motives) and collision-involvement was identified. However, it was verified that participants with low F1-scores and high F2-scores (good skills), were significantly involved in more near misses. This could imply that these participants with poor safety-motives-scores were better able to prevent collisions in case of a conflict. On the other hand, high F4-scores (longitudinal recklessness), were significantly related to collisions. So, high maximum speeds, intensive braking and throttle behavior can indeed be related to collisions. The group of drivers showing high F4-scores can be offered a special training program in order to reduce their chance of being involved in a collision. Since safety measures (F1-scores) could not predict collisions, it is recommended to further investigate the validity of safety measures and the correlation between conflicts and collisions (for a similar discussion see e.g. [17]).

5 Acknowledgements

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6 References

[1] B. Kappé and M.L. van Emmerik, “The use of driving simulators for initial driver training and testing, “ Dutch Ministry of Transportation, 2005. Available:

[2] I. Weevers, J. Kuipers, A.O. Brugman, J. Zwiers, E.M.A.G. van Dijk, and A. Nijholt, “The virtual driving instructor – Creating awareness in a MultiAgent system,” in *Proc. 16th Conf. Canadian Society for Computational Studies of Intelligence*, Halifax, Canada, 2003, pp. 596–602.

[3] I. Weevers, A. Nijholt, J. Kuipers, E.M.A.G. van Dijk, AO Brugman, and J. Zwiers, “A student-adaptive system for driving simulation,” in *Proc. 8th Australian and New Zealand Intelligent Information Systems Conf.*, Sydney, Australia, 2003, pp. 253–257.

[4] J.C.F. de Winter, J. Kuipers, D.W. Venekamp, P.A. Wieringa, M. Mulder, and M.M. van Paassen, "Performance assessment during simulation-based driver training", in *Proc. of the 16th congress of the International Ergonomics Association, Maastricht, The Netherlands (2006)*, accepted for publication.

[5] J. C. F. de Winter, P. A. Wieringa, J. Kuipers, J. A. Mulder, and M. Mulder, “Errors, violations and speed choice in a driving simulator: objective ‘Reason’-ing,” *Ergonomics*, submitted for publication.

[6] W. van Winsum, “From adaptive control to adaptive driver behaviour,” Ph.D. dissertation, University of Groningen, The Netherlands, 1996.

[7] T. Lajunen and H. Summala, “Driving experience, personality and skill and safety-motive dimensions in driver's self-assessments*,” Personality and Individual Differences*, vol. 19, pp. 307–318, 1995.

[8] T. Rothengatter, “Errors and violations as factors in accident causation,” in *Traffic and transport psychology. Theory and application*, T. Rothengatter and E. Carobonell Vaya, Eds. Amsterdam: Pergamon, 1997, pp. 59–64.
[9] J.T. Reason, A. Manstead, S. Stradling, J. Baxter, and K. Campbell, “Errors and violations on the roads: a real distinction?,” *Ergonomics*, vol. 33, pp. 1315–1332, 1990.
[10] L. Evans, *Traffic safety and the driver*. New York: Van Nostrand Reinhold, 1991.
[11] J. Elander, R. West, and D. French”. “Behavioral correlates of individual differences in road-traffic crash risk: An examination of methods and findings,” *Psychological Bulletin*, vol. 113, pp. 279–294, 1993.
[12] J.A. Michon, “A critical view of driver behaviour models: what do we know, what should we do?,” in *Human behaviour and traffic safety*, L. Evans and R. Schwing, Eds. New York: Plenum Press, 1985.
[13] H.H. Molen and A.M.T. Botticher, “A hierarchical risk model for traffic participants,” *Ergonomics*, vol. 31, pp. 537–555, 1988.
[14] H. Summala, “Hierarchical model of behavioural adaptation and traffic accidents,” in *Traffic and transport psychology. Theory and application*, T. Rothengatter and E. Carbonell Vaya, Eds., Amsterdam: Pergamon, 1997, pp. 41–52.
[15] M. Hatakka, E. Keskinen, N.P. Gregerson, A. Glad, and K. Hernetkoski, “From control of the vehicle to personal self-control; broadening the perspectives to driver education,” *Transportation Research Part F*, vol. 5, pp. 201–215, 2002.
[16] T.A. Ranney, “Models of driving behaviour: a review of their evolution,” *Accident Analysis and Prevention*, vol. 26, no. 6, pp. 733–750, 1994.
[17] J.H. Kraay, A.R.A. van der Horst, and S. Oppe, “Handleiding voor de conflictobservatietechniek DOCTOR (Dutch Objective Conflict Technique for Operation and Research),” Institute for Road Safety Research SWOV, Leidschendam, Report R-86-3, 1986.
[18] A.R.A. van der Horst, “A time-based analysis of road user behavior in normal and critical encouters,” Ph.D. dissertation, Delft University of Technology, The Netherlands, 1990.
[19] A.R.A. Horst, “Time-based Analysis of Road User Behavior at Intersections,” in *Proceedings of the third Workshop of International Cooperation on Theories and Concepts in Traffic Safety*, Cracow, 1990.
[20] D. Cooper and N. Ferguson, “A conflict simulation model”, *Traffic Engineering and Control*, vol. 17, pp. 306–309, 1976.
[21] W.A. MacDonalds and E.R. Hoffmann, “Review of relationship between steering wheel reversal rate and driving task demand,” *Human Factors*, vol. 22, no. 6, pp. 733–739, 1980.
[22] E.R. Boer and N.J. Ward, “Event-based driver performance assessment, ” in *Proc. of the Second International Symposium on Driving Assessment, Training and Vehicle Design*, Park City, Utah, 2003, pp. 119–124.
[23] M. Mulder, “Haptic gas pedal feedback for active car-following support,” Ph.D. dissertation, Control and Simulation Division, Faculty of Aerospace Engineering, Delft University of Technology, The Netherlands, 2006.
[24] D. de Waard, “The measurement of drivers’ mental workload,” Ph.D. dissertation, University of Groningen, The Netherlands, 1996.
[25] K.M. Perryman and L.J. Fitten, “Effects of normal aging on the performance of motor-vehicle operational skills,” *Journal of Geriatric Psychiatry and Neurology*, vol. 9, no. 3, pp. 136–141, 1996.
[26] T. Falkmer and N.P. Gregersen, “TRAINER: System For driver Training and Assessment using Interactive Evaluation Tools and Reliable methodologies: DB6.1 Pilot plans,” 2001. Available: http://www.trainer.iao.fraunhofer.de/deliverables/TRAINER%20D6.1_Final.zip
[27] M. Houtenbos, H.M. Jagtman, M.P. Hagenzieker, P.A. Wieringa, and A.R. Hale, “Understanding road user’s expectations: an essential step for ADAS development, “*European Journal of Transport and Infrastructure*, vol. 5, no. 4, pp. 253–266, 2005.
[28] J.A. Michon, *Generic intelligent driver support: a comprehensive study on GIDS*, London: Taylor & Francis, 1993.
[29] D.J. Mundfrom, D.G. Shaw, and T.L. Ke, “Minimum Sample Size Recommendations for Conducting Factor Analyses, “ *International Journal of Testing*, vol. 5, no. 2, pp. 159–168, 2005.

Appendix A
Calculation of TTC_diff

A new safety measure is introduced, to which we referred to as TTC_diff. The calculation of TTC_diff for each time sample is discussed below. For every sample, two circles are fitted through the positions of A and B of the last three samples. The nearest intersection between the two circles is called the collision point (CP) (see Fig. A1). The CP can be interpreted as a possible point of collision if both vehicles keep following the same circular trajectory. Next, the time to collision point (TTCP) is calculated for A and B by dividing the distance to collision point (DTCP, see Fig. A1) by the momentary speed. TTC_diff is calculated by taking the absolute value of the difference between $TTCP_A$ and $TTCP_B$. So, TTC_diff represents the projected time difference of arrival to the CP.

In total, 5 out of the 1676 collisions resulted in a collision. Fig A2 shows the mean TTC_diff versus $DTCP_A$ given that a collision occurred. Here, TTC_diff is expressed in the percentage of intersection encounters which had a higher TTC_diff . Fig A2 can be interpreted as follows. When $DTCP_A$ was 100 meters, approximately 50% of the 1676 intersection encounters had a higher TTC_diff than the mean TTC_diff of the 5 collision courses. In other words, when DTCPA is 100 meters, one cannot tell whether there is increased chance of collision. When $DTCP_A$ is 0 meters, all intersection encounters had a higher TTC_diff than the mean TTC_diff of the 5 collision courses (which should be 0 when $DTCP_A$ was 0 meter). So, when $DTCP_A$ is 0, TTC_diff can predict a collision with absolute certainty.

We used TTC_diff when $DTCP_A$ was 25 meters (TTC_diff25) as a dependent measure. A $DTCP_A$ of 25m was considered reasonably large while giving high discriminability between collisions and non-collisions (96%).

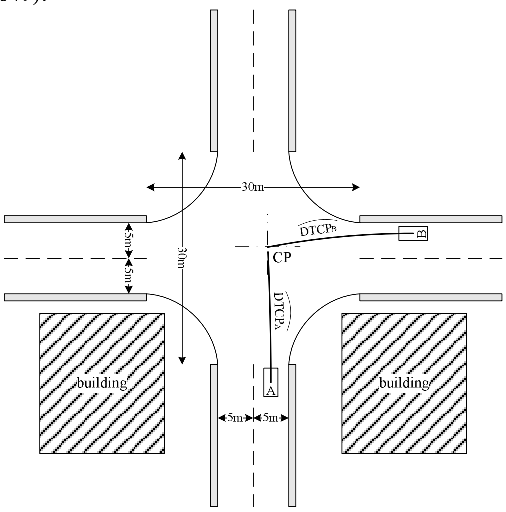

Fig. A1. Schematic top view of intersection. The collision point (CP) is calculated according to the intersection of the circular paths of A and B.

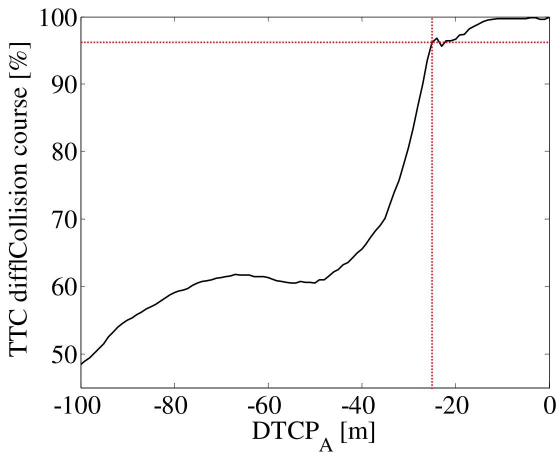

Fig. A2. Mean TTC_diff versus the distance to collision point of A ($DTCP_A$) for the 5 encounters which resulted in a collision. Here, TTC_diff is expressed in percentage of encounters which had a greater TTC_diff. For example, 100% indicates that all encounters featured a larger TTC_diff for the particular $DTCP_A$