You Never Forget How to Drive: Driver Skilling and Deskilling in the Advent of Autonomous Vehicles

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ABSTRACT

In the scope of autonomous driving, the question arises if the increased use of automated systems will have an impact on driver's skills in handling the car in the long term. In order to gain more insights on the issue of driver deskilling and how it relates to driving experience and time intervals of non-driving, we conducted an online survey (n=703). We differentiated between regular drivers, drivers who have stopped driving, and drivers who have started driving again after a longer period of non-driving. We found that initial *skilling* is more of an issue than *deskilling* after long periods of inactively driving. That is, while once learned driving skills seem to remain stable after longer periods of non-driving, they are much more influenced by driving experience in terms of annual mileage and frequency of use. Applied to the autonomous context, this means that drivers must be trained to a high enough skill level or require sufficient manual driving experience, in order to be able to react properly when driving themselves.

Author Keywords

Driving skills; driving experience; autonomous driving.

ACM Classification Keywords

H.1.2 User/Machine Systems: Human factors.

INTRODUCTION

"*Driving skills refer to how good a person is at handling a car*." [1] Distinct driving skills of drivers are a prerequisite for accident avoidance and traffic safety. New drivers normally learn how to drive in driving schools and/or in practice drives with a familiar chaperon. Thereby, driving skills usually increase with the amount of practice. Apart from this human factor, a further approach to reach high road safety is by supporting the driver in his/her driving by providing technological systems in cars, which aim at reducing accidents and increasing safety on the roads. Hence, more and more ADAS (Advanced Driving Assist Systems) are integrated in cars and lots of effort is put in the realization of semi- or even fully autonomous driving (e.g., Google Self-Driving Car[1], Tesla Autopilot[2]).

When it comes to autonomous driving according to NHTSA-Level 3 "Limited self-driving automation" [2], drivers are enabled to cede full control of all safety-critical functions to the car under certain conditions, but they are expected to take back control if conditions change. Hence, drivers still need proper manual driving skills and are required to react properly to situations they face after they take over manual control of the vehicle. This leads to a certain dilemma. On one hand, the skills to drive manually are still required; while on the other hand, the amount of time for carrying out manual driving is reduced, i.e., driving experience decreases. The consequence is that autonomous systems, while supporting the driver and increasing safety, may at the same time lead to degradation in driving skills, which could counteract these benefits.

While we found a number of studies examining driving behaviors and skills (e.g., [14, 16, 17]), these were mostly focused on demographic effects (e.g., gender). None of them specifically examined a loss or decrease of driving skills related to driving intervals or driving frequency. Driven by this problem, we argue that we need to know more about the loss of driving skills in general and how a loss in skills is related to driving experience and/or intervals of non-driving. Which skills are lost or retained? What impact will this have on the mixed traffic world we face in the future and for autonomous vehicle drivers in particular?

Many instruments have been developed over the years to assess drivers' style, behavior, or skills. One of the most frequently used questionnaire is the Driving Skill Inventory (DSI) [15]. We conducted an online survey using the DSI, thereby regarding the driving skills of three target groups: regular car drivers, people who stopped driving a car, and people who started driving a car again after a longer period of non-driving (i.e., months or years). We decided to

[1] https://www.google.com/selfdrivingcar/ 05-27-2016

[2] https://www.teslamotors.com/autopilot 05-27-2016

examine these groups in particular, in order to compare skilled drivers to drivers who can reasonably be expected to have less practice or routine due to inactivity. Since a survey can only assess subjective judgments, we explicitly addressed individuals who started driving again, as those would have an actual frame of reference (i.e., their recent driving experiences) for their judgments. We chose this approach because it allowed us to explore driving deskilling without the need to ascertain certain factors (e.g., time frames of non-driving) in advance, which would be necessary when conducting long-term field studies. Furthermore, it enabled us to promptly gain data for a large sample of different driver groups with varying experiences.

In particular, we wanted to answer the questions, (RQ1) which general insights can we gain with regard to driver deskilling, i.e., how do driving skills (perceptual-motor and safety skills) change with regard to periods of non-driving and driving experience and (RQ2) what are the differences in driving skills between the three groups of regular drivers, drivers, who have stopped, and drivers, who have started to drive again after a longer period of non-driving.

In the following sections, we first outline related work on driver skills and deskilling in general and in the context of autonomous driving. We will then present in detail our methodological approach and results of the online survey, followed by a discussion of our main results.

RELATED WORK

In general, skills can be divided into two main levels, depending on the knowledge they are related to. The *declarative level* is based on propositional or verbal knowledge, whereas the *procedural level* is based on lower-level knowledge [3]. The declarative level is consciously controlled and can be communicated verbally. The procedural level is automated, requires little to no attention, and can be difficult to communicate verbally. According to Rasmussen [3] and Proctor and Dutta [4], normal evolution of knowledge starts declarative and becomes procedurally encoded later on. Declarative encoding is slower and less efficient than procedural encoding and has also been found to have a lower retention rate [5]. Skills can be encoded on only one or both levels, but procedural knowledge has been found to be subject to less decay and still be actionable after declarative knowledge has already been forgotten [6, 7].

Driving Skills

When it comes to driving skills, four different hierarchical levels of the driving task need be taken into consideration [8]. On top, driver's personal motives, personality, behavioral style, and abilities influence the driver's choices or how s/he behaves in certain situations (level 4). On level 3, the decision level, navigational and planning tasks of the driver take place, while level 2 comprises appropriate skills for mastering traffic situations. This means a driver needs to have the knowledge and ability to anticipate and adjust his/her driving in accordance with the constantly changing traffic. Also the knowledge of traffic rules, hazard perception, and interaction with other road users are part of level 2. Basic level 1 is about appropriate vehicle maneuvering. This includes not only basic skills such as knowledge of controls, driving off, braking, or gear changing, but also more complex knowledge such as keeping the car under control, evasive maneuvering, or use of rear-view mirrors. Level 1 and 2 require the driver to execute a set of different skills. Whether these skills are assessed on a declarative or procedural knowledge level, depends on, e.g., experience, or situational context [9].

Influences on Driving Skills

In automotive research, several factors are very frequently researched regarding their influence on distinct driving skills or the overall driving performance. These factors comprise of, e.g., drugs, age, gender, diseases and disorders, or the usage of devices, such as mobile phones or navigation systems, while driving. Besides simulator and field studies, interviews and questionnaires are a very common means to investigate and measure driving skills.

In their 1990s study, Reason et al. [14], for example, assessed driving behavior regarding errors, lapses, and violations with a 50-item questionnaire – the Driver Behavior Questionnaire (DBQ). Their results showed an increase for lapses from age 40 to 45 and both violations and errors from age 45 to 50, although the increase in errors was only a slight one and they did not find an overall increase in errors over the whole age range of 25 to 55. The data is not rich enough to allow any conclusive statements but the results do at least seem to suggest that a deskilling might have taken place among the test subjects from ages 40 onward. The study focused on driving behavior, though, not on distinct driving skills.

The Driver Skill Inventory (DSI) is an instrument to measure drivers' self-reported perceptual-motor and safety skills. It was originally developed by Spolander [15] and, amongst others, further iterated by Lajunen and Summala [16] and Martinussen et al. [17]. *Perceptual-motor* (P-M) *skills* refer to the drivers' ability to technically handle a car, while *safety skills* refer to the drivers' ability to drive in a safe and anticipatory manner. While P-M skills can be associated with level 1 of the driving task as mentioned before, safety skills are rather related to level 2. It was found that drivers with high levels of P-M skills tend to have a riskier driving style and to be more involved in accidents than drivers with high levels of safety skills [17]. Furthermore, it was found that the driving experience serves as a significant predictor of a driver's P-M and safety skills, with experienced drivers having higher P-M but lower safety skills than the average driver [16]. Although relating to advanced drivers in the UK, experienced drivers are able to anticipate and project actions and events further ahead than less experienced drivers [18]. Regarding the influence of gender, Spolander [15] found that male drivers tend to overrate their driving skills.

In a survey with over 3,900 participants, Martinussen et. al. [17] also combined the DBQ with the DSI questionnaire to explore whether drivers' self-reported P-M and safety skill levels are reflected in their self-reported violent driving behaviors, which they found to be true. Drivers, who report low levels of driving skills, report high frequency of violent driving behaviors and vice versa.

Autonomous Driving and Driving Skills

Autonomous driving fundamentally changes the way in which individuals operate a car, from an active driving to a monitoring role [10]. In autonomous and mixed traffic situations, drivers need to be able to do both – monitor the autonomous system, as well as drive manually, when the need for a handover arises. This ability to drive manually can be affected negatively by driver assistance systems, as Brookhuis and de Ward [11] found. Relying on assistance systems can lead to complacency [12] and a decrease in ability or skills [13]. It can be assumed that the more an individual operates a vehicle in an autonomous mode, the less that individual is capable of manually operating the vehicle during critical situations due to deskilling. However, at the time of this writing, there were no studies or publications known to the authors, which examined the development of driving skills over time in the autonomous driving context in greater detail.

METHOD

In order to shed some light on the possible decrease in driving skills in the upcoming age of autonomous vehicles, we developed an online questionnaire consisting of 56 questions allotted to three different parts.

As we were mainly interested to find out how driving skills are influenced by *time intervals of non-driving* and driving experience in terms of *annual mileage* and *frequency of use*, the online questionnaire was designed to address three different driver groups: 1) *Regular drivers*, i.e., drivers, who drive a car regularly or in regular intervals, 2) *Stopped drivers*, i.e., drivers, who haven't been driving a car for a longer period of time (i.e., months or years), and 3) *Start again drivers*, i.e., drivers, who have started driving a car again after a longer period of time (i.e., months or years) of not driving.

The questionnaire was designed in a flexible way, i.e., depending on the subject's affiliation to one of the groups, the subsequent questions were chosen and displayed accordingly. The assignment to the groups was based on subjects' individual self-assessment.

First, all subjects were asked some general questions regarding age, gender, the year their driving license was obtained, and usual means and frequency of transportation. Then, subjects had to indicate to which of the groups mentioned above they belong. Depending on the answer, the subjects were asked follow-up questions. For example, *regular drivers* were asked, which car they drive, and which assistance systems they use in their car, while *stopped or start again drivers* were asked for their specific reasons, which led them to stop or restart driving.

In the main part of the questionnaire, we used the DBQ [14] and DSI [16, 17], which are very frequently used and well-tested research instruments in the automotive research domain, in order to gather reliable, well-grounded data on the driving skills and driving behavior of the participants. In the DSI, drivers indicate their perceptual-motor and safety skills by comparing themselves to an average driver. This is done on a five-point scale with 0=well below average and 4=well above average. The DSI was applied in all three groups, while the DBQ items only needed to be answered by *regular* and *start again* drivers, as here the focus is on actual driving behavior in terms of frequencies of occurrence during the last year. Note that in this paper, we solely focus on results from the DSI.

In the third part of the questionnaire, subjects were then asked about their driving habits, i.e., annual mileage, purpose of car use, and specific questions, e.g., regarding number of accidents or tickets, or whether they have completed any driver safety trainings.

The online-questionnaire was translated to German and French and distributed by Universities of Salzburg and Luxembourg via various channels, such as mailing lists, and social media. Filling-in the questionnaire lasted between 10 and 20 minutes. Among all participants, ten Amazon vouchers, worth 20 Euros each, were raffled off as an incentive. The questionnaire was online for almost one month in February/March 2016.

RESULTS

The statistical analysis of the data was done with IBM SPSS Statistics Version 21. Overall, we received 703 fully completed questionnaires (890 in total, the dropout rate was 21%). The number of female participants was 406 (57.8%) and 297 were male (42.2%). The youngest subject was 17, the eldest 76 years old (M=33.7, SD=13.6). Most questionnaires were filled out in German (n=605, 86.1%), 7.8% (n=55) in French, and 6.1% (n=43) in English. All subjects had a driving license; the earliest was obtained in 1961, the latest in 2016. A majority of subjects obtained their driving license in Austria (62.3%), followed by Germany (22.0%), France (5%), Italy, Luxembourg (2.4% each), Belgium (1.7%), or in one of 21 other countries (e.g., Spain, Romania, Russia, USA).

Most participants indicated to be regular drivers (88.9%, n=625), 60 drivers had stopped driving for a long period (8.5%), and 18 drivers had started driving again after a long period of not driving (2.6%).

Regarding ADAS in the cars of active drivers, 45.7% had cruise control and 36.5% parking sensors. More sophisticated ADAS, like lane keeping assistant (4.0%), parking assistant (3.7%), or adaptive cruise control (2.8%), were rather rare in the sample. Only 14.6% were driving with automatic transmission.

General Differences in Driving Skills

In a first step, we wanted to find out how the three different groups of drivers (i.e., regular, stopped, start again) differ in their self-reported driving skills. Due to the huge difference in sample size between the regular drivers and the other two groups, we drew a random sample of n=60 out of the 625 regular drivers, which was used for comparison with the other two groups.

The mean age of the subjects in each group was comparable, i.e., 32 years for regular, 31 years for stopped, and 33 years for start again drivers ($F_{(2,135)}$=0.220, n.s.). The gender distribution was approximately 62% female and 38% male in the *regular* and *stopped* driver groups. For the *start again* drivers, the distribution was 83% female and 17% male. Subjects of this group have started driving again after 3 months to 6 years (median=2 years). The median annual mileage for regular drivers was 10,000 km/year, *stopped* drivers reported that they drove 1,000 km/year before they stopped driving and for start again drivers the current median annual mileage was 1,150 km/year.

A one-way ANOVA was computed to compare the three groups with regard to perceptual-motor (P-M) and safety skills (prerequisites with regard to normal distribution and variance were given, i.e., Shapiro-Wilk and Levene tests n.s.). We found a highly significant effect for P-M skills ($F_{(2,134)}$=30.218, p<.001, η^2=0.311), whereas we could not find any significant differences for safety skills ($F_{(2,133)}$=0.824, n.s.).

Post-tests were computed using GT2 Hochberg, which is robust to unequal sample sizes. We found that the group of *stopped* (M=1.58) and *start again* drivers (M=1.71) reported significantly lower P-M skills compared to regular drivers (M=2.42, all p<.001), while there weren't any significant differences in reported P-M skills between the *stopped* and *start again* drivers. Thus, *stopped* and *start again* drivers rated their own PM-skills below the average (i.e., a value of 2 on the DSI scale), whereas regular drivers' self-assessment is above this average. Safety skills were rated above average by all three groups. Table 1 provides an overview of means and standard deviations of P-M and safety skills in the three groups.

Group	n	P-M skills	Safety skills
Regular drivers	60	2.42 (0.51)	2.55 (0.50)
Stopped drivers	60	1.58 (0.71)	2.57 (0.54)
Start again drivers	18	1.71 (0.55)	2.73 (0.51)

Table 1. Means and standard deviations of P-M and safety skills of the three groups of drivers.

As we were interested to find out whether there is a lack in very specific P-M skills, we also took a look at each item of the P-M skills (see Table 2 for an overview). We found that the overall difference between the groups is reflected in each item, i.e., for every item we could find a significant (*) higher rating of regular drivers in comparison to stopped and start again drivers and no significant difference between the latter two. It is further apparent that regular drivers judged every skill, except "Driving in a strange city" above average.

P-M Items	Regular	Stopped	Start Again
Perceiving hazards in traffic*	2.80 (0.66)	2.08 (0.96)	2.33 (0.77)
Prediction of traffic situations ahead*	2.75 (0.82)	1.93 (1.10)	2.00 (0.59)
Controlling the vehicle*	2.65 (0.71)	1.78 (1.03)	2.06 (0.73)
Fast reactions*	2.60 (0.76)	1.93 (1.07)	1.89 (0.58)
Knowing how to act in particular traffic situations*	2.58 (0.72)	1.95 (0.98)	2.06 (0.73)
Fluent driving (management of your car in heavy traffic)*	2.55 (0.72)	1.45 (0.93)	1.78 (0.94)
Driving fast if necessary*	2.48 (0.93)	1.62 (0.96)	1.89 (0.83)
Performance in critical situation*	2.47 (0.75)	1.45 (0.96)	1.44 (0.78)
Making firm decisions*	2.38 (0.76)	1.88 (1.04)	1.67 (0.59)
Managing the car through a skid*	2.27 (0.86)	1.37 (1.06)	1.39 (0.92)
Fluent lane-changing in heavy traffic*	2.25 (0.93)	1.40 (1.03)	1.44 (0.71)
Driving in the dark*	2.22 (0.85)	1.53 (1.02)	1.50 (0.79)
Overtaking*	2.07 (0.94)	1.27 (0.86)	1.28 (0.83)
Driving in a strange city*	1.87 (0.93)	0.98 (0.93)	1.28 (0.90)

Table 2. Means and standard deviations of P-M skills items for each of the three groups of drivers.

Similarly, we also took a closer look at the safety items (see Table 3). Here, we could only find a significant difference with regard to the item "Conforming to the speed limits", where regular drivers had significantly lower judgments (M=2.03) than stopped (M=2.70) or start again drivers (M=2.94, p<.01). In contrast to the P-M items, we could find that all items except "Tolerating other drivers' blunders calmly" were rated above average in all three groups.

Safety Items	Regular	Stopped	Start Again
Paying attention to other road users	2.95 (0.59)	2.55 (1.02)	2.67 (0.84)
Avoiding competition in traffic	2.77 (1.03)	2.83 (1.09)	3.11 (0.96)
Driving carefully	2.75 (0.75)	2.52 (0.97)	2.94 (0.80)
Avoiding unnecessary risks	2.75 (0.80)	2.70 (1.08)	2.83 (0.99)
Keeping sufficient following distance	2.65 (1.13)	2.83 (0.94)	3.00 (0.69)
Obeying the traffic lights carefully	2.63 (0.84)	2.63 (1.01)	2.89 (0.83)
Adjusting your speed to the conditions	2.60 (0.76)	2.33 (0.91)	2.61 (0.92)
Conforming to the traffic rules	2.55 (0.77)	2.53 (0.91)	2.56 (0.78)
Relinquishing legitimate rights (e.g., right of way) when necessary	2.38 (0.89)	2.38 (0.94)	2.61 (0.85)
Tolerating other drivers' blunders calmly	2.05 (0.93)	1.98 (1.23)	1.89 (1.02)
Conforming to the speed limits*	2.03 (1.10)	2.70 (0.91)	2.94 (0.80)

Table 3. Means and standard deviations of safety skills items for each of the three groups of drivers.

Impact of Periods of Non-driving on Driving Skills

In a next step, we took a closer look at the drivers, who have not been driving for a longer period of time (n=60). The time intervals since they stopped driving varied between one month and 40 years (median=1.29 years). The time interval in which they had been driving before stopping varied between zero months (indicating subjects stopped immediately after getting the driving license) and 35 years (median=4 years).

We found a significant weak correlation (Spearman-Rho=.333, p<.01) between the time interval subjects have been actively driving and the P-M skills. This indicates that the longer subjects were engaged in driving before stopping, the higher they considered their P-M skills. We could not find a significant correlation for safety skills. We also took a look at the annual mileage before subjects stopped driving. The annual mileage varied between 0 and 50,000 km/year (median=1,000 km/h). Here, we could find a significant medium correlation (Spearman-Rho=.506, p<.001) for P-M skills and a weak correlation for safety skills (Spearman-Rho=.275, p<.05).

These results suggest that the more subjects were engaged in driving before stopping, the higher they rate their skills. As we found that a longer time interval of driving and annual mileage are confounding (Spearman-Rho=.384, p<.01), we also calculated partial correlations. Indeed, we could find that the correlation of the time interval with P-M skills vanishes, if it is controlled for annual mileage, while the correlation between annual mileage and P-M skills (r=.413, p<.01) remains stable, when controlling for the time interval.

We further took a look at the amount of time passed since subjects had stopped driving. We could not find a significant correlation with the judgment of P-M or safety skills, which indicates that previous driving experience is the more relevant factor and less the period of non-driving.

We also correlated the ratings of each item of the P-M and safety scale with the amount of non-driving, in order to check if there is a decrease for specific skills. We could not find any significant correlations, except for the P-M item "Knowing how to act in particular traffic situations". Here we could find a significant negative correlation (Spearman-Rho=-.264, p<.05), indicating that the more time has passed, the lower drivers rate this skill. The correlation is weak, though.

In order to check if there is an interaction effect between the annual mileage before stopping and the amount of non-driving time, we formed two groups for each factor (based on a median-split) and calculated a two-factorial ANOVA. In line with the results from the correlation, we only could find a significant effect for annual mileage before stopping ($F_{(1,56)}$=14.701, p<.001, η^2=0.208) with regard to P-M skills. This means that subjects with more than 1,000 km/year mileage before stopping rated their skills significantly higher (M=1.99) than subjects with less annual mileage (M=1.31). No significant effects could be found for safety skills.

Regular Drivers and Driving Skills

We further investigated how the driving skills of the group of regular drivers (n=625) are influenced by the duration of active driving periods and driving experience. Subjects in this group have been driving a car between one and 55 years (median=11 years) with an annual mileage between 15 and 120,000 (median=10,000). We could not find any significant correlation between the amount of driving time and P-M or safety skills. In order to closer examine the influence of annual mileage on driving skills, we made a percentile-split, specifically comparing the first (0-25%), second (25-50%), third (50-75%), and fourth (75-100%) quartile (cf. Table 4 for km/year numbers).

A one-way ANOVA was calculated to compare the P-M driving skills for these percentiles. We found a significant effect for annual mileage with regard to P-M skills ($F_{(3,621)}$=25.617, p<.001, η^2=.110). GT2 Hochberg posttests revealed that subjects in the first (M=2.32) and second quartile (M=2.38) rated their P-M skills equally high (i.e., subjects driving less than or equal to 10,000 km/year). Subjects in the third quartile rated their P-M skills significantly higher than subjects in the first (p<.001) and second quartile (p<.05) and subjects in the fourth quartile rated their P-M skills significantly higher than all other groups (all p<.001). Table 4 provides an overview of means and standard deviations for P-M and safety skills in the different groups.

Quartile	n	P-M skills	Safety skills
First: <= 5,000 km/year	181	2.32 (0.55)	2.65 (0.52)
Second: > 5,000 and <= 10,000 km/year	134	2.38 (0.53)	2.66 (0.51)
Third: > 10,000 and <= 20,000 km/year	190	2.55 (0.53)	2.53 (0.46)
Forth: > 20,000 km/year	120	2.85 (0.56)	2.58 (0.58)

Table 4. Means and standard deviations of P-M and safety skills for different annual mileage quartiles.

As the prerequisite of variance homogeneity was not given for safety skills (Levene F=3.838, p<.05), a Kruskal-Wallis-test was computed to compare the safety skills for the four groups. We could find a significant effect (Chi^2=8.941, p<.05). Post-tests were calculated using the Mann-Whitney-test and a corrected alpha of 0.05/6=0.008 was assumed for each comparison. We found no significant difference for the first (M=2.65) and second quartile (M=2.66) in safety skills. However, we found that safety skills were rated significantly lower in the third (M=2.53) and forth quartile (M=2.58) compared to the first and second quartile (all p<.001).

We were further interested to find out how frequently drivers are driving with their car and how this influences their driving skills. As apparent in Figure 1, daily usage of the car is most distinctive in the fourth quartile (69.2% of

drivers in this group use their car daily), followed by the third quartile with 45.8% daily usage, while the amount in the second and first is comparably low. Hence, the groups with higher mileage are also characterized by a more frequent use of their cars (i.e., it's less the case that a high mileage is gained through few drives with a high amount of driven km).

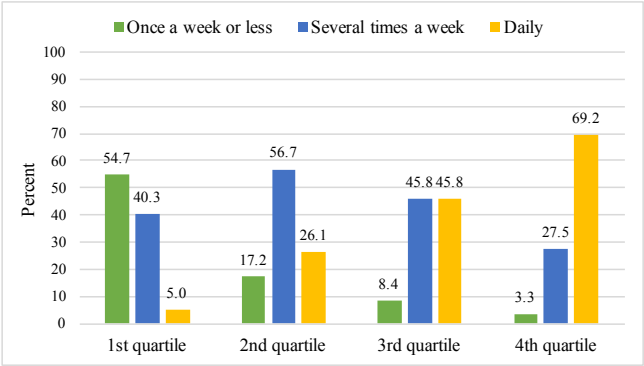

Figure 1. Frequency of using a car for the first, second, third and fourth quartile of annual mileage.

Indeed, we found that a higher frequency of driving a car led to higher ratings of P-M skills ($F_{(2,622)}$=24.408, p<.001, η^2=.073). That is, subjects driving their car once a week or less rated their P-M skills (M=2.28) significantly lower than subjects using it several times a week (M=2.47, p<.01) or daily (M=2.69, p<.001), with also a significant difference between the latter two (p<.001). We could not find any significant effect for safety skills ($F_{(2,622)}$=2.815, n.s.).

DISCUSSION

Our results suggest that driving skills are first and foremost influenced by driving experience in terms of annual mileage and frequency of use. In particular, this influence can be found for P-M skills (i.e., technical driving skills), while safety skills (i.e., the ability to drive in a safe manner) are much more stable. Taking into consideration that safety skills rely more on attitudes and personality factors, which are rather stable traits, this is not surprising [8].

General Insights with regard to Driver Deskilling

With regard to our first research question, we found that the duration of periods of non-driving had no influence on the driving skills, suggesting that it does not matter for how long someone has not been driving. What is more relevant is the driving experience gained in advance. Similarly, the duration of periods of active driving has only an influence, if it is associated with a higher number of driven kilometers.

Our interpretation with regard to deskilling, though, needs to be done with some caution. In our sample, drivers who have stopped driving were primarily characterized by an overall lower annual mileage when they were still driving compared to regular drivers. We could not find a decrease in driving skills depending on the time interval they have not been driving. It remains unclear whether there would be an influence if the initial level of driving experience were higher. However, in line with Anderson or VanLehn [6, 7], who argue that procedural knowledge decays less, we would assume that the level of driving skills, should remain rather stable over time. It is more likely that declarative knowledge regarding, for example, the meaning of traffic signs gets lost over time.

It is interesting that the single item analysis yielded only one negative weak correlation between the item "Knowing how to act in particular traffic situations" and the amount of non-driving time. Cautiously interpreted, this could reflect the loss of declarative knowledge, as opposed to the other P-M items, the knowledge of certain traffic regulations or signs is more relevant in order to act properly. However, we believe further research is needed when it comes to deskilling with regard to this knowledge.

Differences in Driving Skills between Regular, Stopped, and Start Again Drivers

When comparing the regular, stopped, and start again drivers, we found that regular drivers rated their P-M skills significantly higher than stopped and start again drivers, while the latter two did not differ in their ratings. An important point here is that stopped and start again drivers actually see their P-M skills beneath an average driver. In contrast, safety skills were equal and rated above average in all three groups.

We would have assumed that drivers who had started driving again, would have had higher skills ratings than stopped drivers. In particular, because they have been active for 2 years (=median) in driving again. There are several explanations for this. First, this group was also characterized by a low annual mileage (comparable to stopped drivers). Given the huge influence of this factor as outlined by our further results, we believe that this mainly led to no difference to the stopped drivers. Of course, another point is that start again drivers could make their judgment based on actual experiences, while stopped drivers needed to anticipate and, therefore, might have overestimated their P-M skills in general. Furthermore, it should be noted that the gender distribution in this group differed from the others, with a comparably lower amount of male drivers who tend to overestimate their driving skills compared to female drivers [15].

Interestingly, we could find a distinction between the three groups for every single P-M item, which was in line with the overall results. Every P-M skill was rated higher by regular drivers, when compared to the other two groups. This indicates that an influence of driving experience takes place in all ranks, i.e., fluent driving, performance in critical situations, perceiving hazards, fast reactions, controlling the vehicle, and so on.

Regarding safety skills, the only outstanding item was "Conforming to the speed limits", where stopped and start again drivers had significantly higher ratings compared to

regular drivers. An explanation for this could be that with increasing driving experience, car drivers' confidence in their own driving skills is outbalancing the need to obey to certain traffic rules, such as speed limits, while inexperienced drivers rather rely on traffic rules than their own abilities.

Driving Experience – The Crux of the Matter

Our results suggest that driving experience in terms of annual mileage and frequency of use are the most important factors influencing the driving skills. For stopped drivers, we found that the annual mileage before stopping driving positively correlated with the P-M skills. Among the group of regular drivers, we could find that drivers driving more than 10,000 km/year had higher ratings in P-M skills when compared to drivers with lower mileage and that P-M skills were even higher for driver with a mileage of more than 20,000 km/year. On the other hand, our data revealed that safety skills are significantly rated lower for drivers with more than 10,000 km/year compared to drivers with less mileage. This is in line with the findings of Lajunen and Summala [16], who found that inexperienced drivers emphasize safety-motives more than experienced drivers.

Furthermore, we found that it makes an overall difference with regard to P-M skills if someone is driving daily, several times a week, or once a week or less. The lower the frequency of driving is, the less distinct the P-M skills are. We are aware that in our sample frequency of driving and annual mileage were coherent to a certain degree. Nonetheless, we believe it's interesting that it already makes a significant difference if somebody has daily driving practice or less.

Meaning of the Results in the Context of Autonomous Driving

This study was primarily motivated by the assumption that the use of autonomous systems could lead to a degradation in driving skills over time, which could then lead to longer reaction times and erroneous execution of driving maneuvers in handover situations. The intention was then to analyze which skills would deteriorate more than others, with the eventual aim to develop interaction design solutions that specifically target and maintain or improve these skills. Such design solutions could then, e.g., aid to keep the driver "in the loop" during semi-autonomous and mixed traffic situations of the future [19]. Our results suggest, however, that deskilling is less of an issue than the initial skilling.

Our data shows that every manually driven kilometer counts when it comes to acquiring driving skills. These initially acquired skills are most important when it comes to safe and skillful driving later on, even after longer periods of driving inactivity. But what if the car takes over for most of these kilometers, which would have built up a driver's skills in a manual driving environment?

Assuming that future drivers might drive in autonomous mode from the outset after gaining their driver's license, the amount of manual driving will be lower overall, which means that initial driving skills would also be much lower for the average individual. Hence, the amount of practice and driving routine required until a certain level of driving skills is reached will be much higher – if that level can be reached at all. Possible solutions to this issue could be policy-based, where a certain amount and kind of training in a manual vehicle is necessary before a driving license for autonomous vehicles can be obtained. Another solution could be a persuasive system, which provides a "training mode" and allows the driver to practice simulated maneuvers during autonomous driving modes.

We believe that future work in this direction is necessary, so that adequate driver skilling in the driving environments of the near future can be ensured. Otherwise, there is a risk that the perceived increased levels of safe driving with respect to autonomous vehicles will not be as high as anticipated.

Limitations

Since the study was realized as an online questionnaire study, the data collected ultimately relies on the individuals' subjective assessment. While choosing this method meant access to a broad range of individuals and data, it also means that the results we gained are subject to each individual's honesty and their capability to adequately judge their own abilities. It should be mentioned that this can be considered a standard issue and is true for all methods, which rely on reporting.

In our sample, we could observe that drivers tended to estimate their skills above an average driver (indicated by mean ratings over a value of 2) in almost all cases. This phenomenon is most likely the result of a 'positive-self' bias, i.e., a self-enhancement bias in which individuals tend to attribute any positive characteristics to themselves [20]. However, the opinions about the mechanisms underlying this bias differ in literature (see, e.g., [21]).

It should be noted that we also captured which ADAS drivers use in their car in our study. A conclusive analysis if using such systems had an impact on driving skills could not be carried out as the number of users of such systems were low in our sample and the drivers characterized by particular high driving experience.

As our survey was disseminated internationally, English DBQ and DSI items had to be translated into German and French. While particular care was taken to ensure accurate translations, misinterpretations due to lingual or cultural differences cannot be excluded completely.

CONCLUSION

In this paper, we have reported on an online survey that asked for perceived driving skills in regular drivers, drivers who have stopped driving, and those who have started driving again. Our results show that perceptional-motor

skills are learned and retained for some time. Thereafter, these skills are perceived to be stable. Based on our results, we can draw the conclusion that driving resembles riding a bike – and as the saying goes: "You never forget how to ride a bike." The challenge that comes along with this is that if you have not learned it properly once, you won't master it later on.

Therefore, we argue that it is crucial that drivers still receive appropriate training to a sufficient level so that they are able to resume control in hand-over situations. Once drivers are sufficiently skilled, the manual handling of a vehicle is perceived to be feasible. Future work will focus on what skill level is required for a driver to be sufficiently skilled so that they can react appropriately when they receive the feared "Please take over!" message.

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