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Psychophysical fitness and driving performance of older drivers



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Introduction

In the European Union the share of people over 80 years is expected to triple until 2060 [1]. This demographic change also affects road traffic. For example, for the OECD countries the share of older driver is expected to double until 2050 [2]. Furthermore, future older drivers drive more than the current generation does [3]. Given the importance of driving for their independence and participation in society the question rises how safe they drive in traffic.

In general accident data show no significant risk for older drivers. However, the accident risk in relation to the distance driven significantly rises at the age of 75 and even further at 85 [4]. But more important the risk to cause an accident is significantly higher in old age. Older drivers cause accidents more often at junctions especially when turning left [5]. These situations are complex and demand cognitive resources and the ability to act. In contrast accidents due to traffic violations such as speeding or drunk driving decrease with age. More often are violations due to lack of attention such as ignoring other's right of way [4].

In real traffic the appraisal of older driver's driving performance is less obvious. They compensate for their declining driving ability by e.g. reducing their speed, choosing familiar routes, avoiding rush hours etc. Furthermore, age as indicator does not describe the psychophysical state of elderly precisely. The older people are the more heterogonous they are in their sensory, cognitive and motoric competencies and performance. Therefore, the aim was to assess older drivers driving performance on the basis their cognitive, sensory and motoric abilities and performance i.e. their functional age.

Two studies were conducted. In both studies we analyse the sensory, cognitive and motoric performance of older car drivers, their driving performance and its relations. In the first study we analysed driving performance in a test drive, in the second study a driving simulator. The reason is that in every driving we were not able to observe critical situations that put elderly to their limits, nor could we get them into such situations for safety reasons. Therefore, in the second study they drove a similar test track in a driving simulator where critical situation could be manipulated.

Methods

Sample

The sample consisted of four age groups with person younger than 55 years serving as comparison group (see table 1). The group of elderly drivers was further divided in three age groups. Altogether 232 drivers took part of which 179 drivers were aged 65 or older. All of them hold a valid driver license and were active drivers. About 80 percent were male. There was no statistically significant difference between age group in their mileage driven per year. Only in study 1 and only the oldest age group reported more accidents (including minor accidents) compared to the other groups. The procedure was similar in both studies. Participants complete first the psychophysical tests and subsequently drove the test drive or driving simulator scenario respectively.

Sample description

Table 1 · **Main characteristics of participants of study 1 and 2**

	Study 1				Study 2				
	age group	n	mean	min-max	mileage (km/year, M/SD)	n	mean	min-max	mileage (km/year, M/SD)
0	<55 years	26	38	27–53	18,368 (17,633)	27	45	35–55	11,519 (10,018)
1	64–69 years	41	67	64–69	15,962 (11,874)	29	67	65–69	8,862 (9,404)
2	70–74 years	29	72	70–74	12,154 (7,512)	34	72	70–74	10,118 (4,068)
3	>75 years	18	79	75–90	12,632 (7,712)	28	79	75- 86	8,100 (4,733)
	Overall	**114**				**118**			

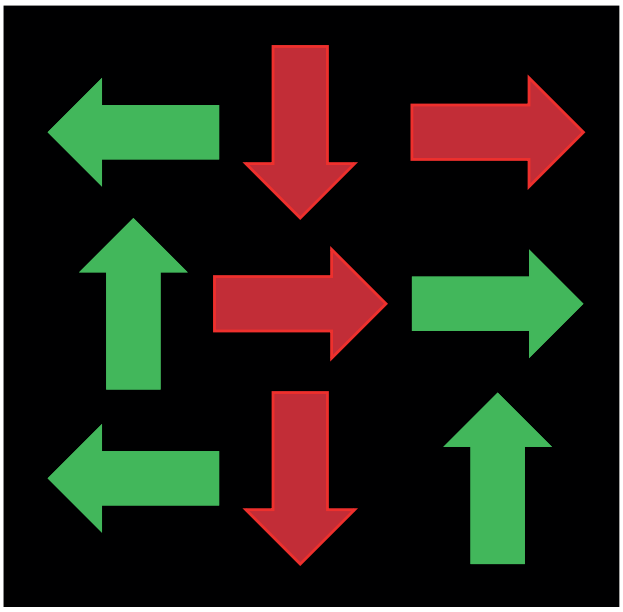
Psychophysical tests (Study 1 and Study 2)

In both studies participants completed several psychophysical tests. The main sources for these tests were the Vienna Test System TRAFFIC by Schuhfried (short: VTS), the Leibniz Research Centre for Working Environment and Human Factors at TU Dortmund (short: IfADo) and own developments (short: TUD). Some of the VTS tests are part of current legal driver testing procedures. In addition people filled in a questionnaire about demographics, current state, self-assessment of driving style and driving competencies. Altogether it took about 60 to 70 minutes. Table 2 and picture 1 describes the variables and their measurements. The colour vision test was used as screening for red-green colour blindness. Tests that did not yield any differences between the age groups in the first study were not included in the second study, for example the attitude tests. Other tests such as the motility tests were included following the results of the first study.

Methods

Table 2 · **Variables and measurements included in study 1 and 2**

Variable	Measurement	Study 1	Study 2
Sensory performance			
Visual acuity	ETDRS charts, Landolt C according to DIN EN ISO 8596	x	x
Peripheral perception	PP (VTS)	x	x
Contrast vision	ETDRS charts, Contrast Sensitivity Test	x	x
Colour vision	Ishihara Color Blindness Test	x	x
Age-related macular degeneration	Amsler Grid	x	
Cognitive performance			
Attention (divided, selective, processing speed)	UFOV Test (Visual Awareness Inc.)	x	x
Distraction (interference)	Stroop Task Block 2 (Test 401, IfaDo)	x	x
Distraction (inhibition)	Go NoGo Task (Test 601, IfADo)	x	
Visual Search	Visual search (Test 701, IfADo)	x	x
Concentration	COG S11 (VTS)	x	
Obtaining an overview – traffic	ATAVT S1 (VTS)	x	x
Motor abilities			
Physical fitness	Observation by experimentar (TUD)	x	x
Eye-hand coordination	2Hand S3 (VTS)	x	
Responsiveness	RT S3 (VTS)	x	
Motility (Head)	Neck Rotation Test		x
Motility (Walking)	Rapid Pace Walk Test		x
Attitudes			
Readiness to take risks in traffic	WRBTV (VTS)	x	
Adventurousness and need for excitement	IVPE (VTS)	x	
Sense of responsibility	IVPE (VTS)	x	
Self control	IVPE (VTS)	x	
Emotional stability	IVPE (VTS)	x	



Picture 1 · Example of visual search test (IFADO). Participants are requested to press a button if they detect a green arrow pointing upwards or a red arrow pointing to the right. The target is present in half of all runs.

Test drive

The participants drove with an instrumented car which measured GPS, CAN-Bus data and eye tracking data (see picture 2). Road characteristics of the test drive such as cross-section or bendiness were measured beforehand with a surveying car. It also took stereo pictures every five minutes. The various data sources were combined and synchronized before the actual analysis.

The first part of the test drive of about 3.8 km while driving to the motorway access was used to get familiar with the car. This stretch was not included in the analysis. The track consisted of an urban, interurban and motorway stretch. They were selected to reproduce demanding driving situations especially for elderly car drivers. The urban stretch included a number of complex junctions. The interurban stretch was about to test speed adaptation to changing circumstances such as curves, localities, speed limits. On the motorway stretch we wanted to observe overtaking and speed adaption on roads without speed limits. This stretch was especially



Picture 2 · Instrumented car for test drives

suitable since there is mostly no speed limit, moderate but almost certain truck traffic and low traffic density. Therefore we expected overtaking manoeuvres also by defensive drivers. In the following we describe relevant situations along the test track for the analysis of elderly driving performance.

Urban stretch:

1. Junctions with a Give way sign and crossing of a priority street (1a/1b)
2. Junctions with left yields to the right (2a: half hidden, 2b: visible)
3. Turning at a turning loop which required careful traffic observation
4. Turning right at a traffic light (4a/4b)
5. Turning left at a junction with a Give way sign

Interurban stretch:

6. Well-constructed road stretch with a speed limit of 70km/h due to various T-junctions
7. Badly-kept road stretch with speed limit of 70km/h due to the state of preservation
8. Little-used narrow road stretch with tips and troughs
9. Newly constructed broad straight road stretch continuously rising, no speed limit except for one locality at about half of the road stretch with speed limit of 70km/h
10. Situated between the urban and motorway stretch, speed limit only near the motorway access

Motorway stretch:

11. Two-lane motorway stretch with a speed limit of 100km/h before and suspension thereof after the tunnel
12. Two-lane motorway stretch with a speed limit before and suspension thereof after a motorway access

Driving simulator scenario

In the driver simulator scenario we wanted to investigate driver's reaction to unforeseen events, complex situations with and without time pressure. The scenario was an urban scenario (picture 3).



Picture 3 · Driving simulator scenario

The following events were included:

13. A bicyclist changing from the side stripe to the driver' lane demanding the driver to either brake or to evade. This event was to introduce participants to the kind of events they were about to encounter and therefore, was excluded from the analysis.
14. On the opposite lane behind an on-coming bus another car not visible to the driver veered into the drivers lane (14a: without, 14b: with distraction)
15. A STOP sign requested driver to brake and stop before carrying on. The reaction to the first clearly visible sign served as baseline for reaction to the second sign. That was masked by a parking bus and required an immediate reaction.
16. Turning left on a junction. Drivers were requested to choose a suitable gap between oncoming traffic, to press the button when they would have started to turn and to carry on driving straight (16a: without, 16b: with on-coming bicyclist on the opposite side stripe)

17. Pedestrian crossing the lane from the left demanding the driver to brake sharply. The pedestrian was hidden by a parked car and only visible after stepping out on the lane (17a: without, 17b: with distraction).
18. A parked taxi changes to the lane, drives slowly about 30m and changes back to the side-stripe (18a: without, 18b: with distraction)

To simulate distraction participants were requested to carry out one out of two secondary tasks and to announce the answers to the experimenter. These were:

A count bicyclists on the right side and
B to identify the nearest location from a number of place-name signs. Participants completed a trial of about 800m before the actual simulation, practicing the secondary tasks, the turning left manoeuvre and braking at the STOP sign.

To avoid drop outs due to simulator sickness we did not asked participants to physically turn but to press a button instead and to keep on driving. Furthermore situations that required sharp breaking were placed at the end of the scenario. Also the simulation was presented on a middle screen only. Two peripheral screen usually part of a driving simulation were not used. That is to avoid a dissonant sensory input which contributes to simulator sickness [6]. As a result the dropout rate was only 8 percent.

Results

In the following sections we present age-relate differences in the psychophysical tests, the driving performance and the prediction thereof. From the psychophysical tests and driving situations described above we only present those that yield statistically significant effects on at least 5 percent level.

Age related differences in sensory, motoric and cognitive performance (study 1 and study 2)

Table 3 presents age-related differences in psychophysical tests. Only those variables are presented where there were statistically significant differences between age groups. For example, there is a difference between age groups in visual acuity in both studies. In study 1 the comparison group shows higher visus scores compared to age group 2 and 2, in the second study compared to all three age groups. For distraction (i.e. the Stroop test) there is an age-related difference in the first study and partly in the second study. In the first study differences in mean reaction time for correct and incorrect answers as well as compatible and incompatible stimuli are significant, in the second study only the latter. In the first study the comparison group reacts faster compared to all other age groups for correct as well as incorrect answers. For compatible and incompatible stimuli all four age groups differ with reaction time rising in ascending order. In the second study only the comparison groups reacts faster compared to all three age groups for compatible stimuli and compared to age group 2 and 3 for incompatible stimuli.

In summary there are considerable age-related deteriorations in line with the literature. Most notably in the first study 40 percent of drivers aged 75 years and older exhibit a visus score of below 0.7. This is the cut off for visual acuity in the driver licence regulation [7]. In the second study only 3.6 percent of that age group failed the cut off highlighting the large variance of psychophysical abilities in old age. In addition the answer to the questionnaire show a rather realistic self-perception of drivers own abilities compared to the same age group and younger age groups.

The results also illustrate that psychophysical abilities change differently (see picture 4). By tendency there is a linear decline for sensory functions. On the other hand cognitive functions exhibit a sudden decline (as indicated by an increasing reaction time in picture 4, right side). Statistically significant effects are manifest mostly at age 75 and older.

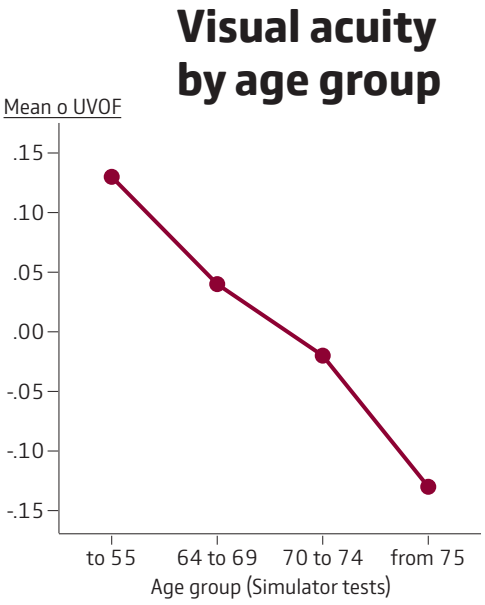
Decreasing psychophysical fitness with age

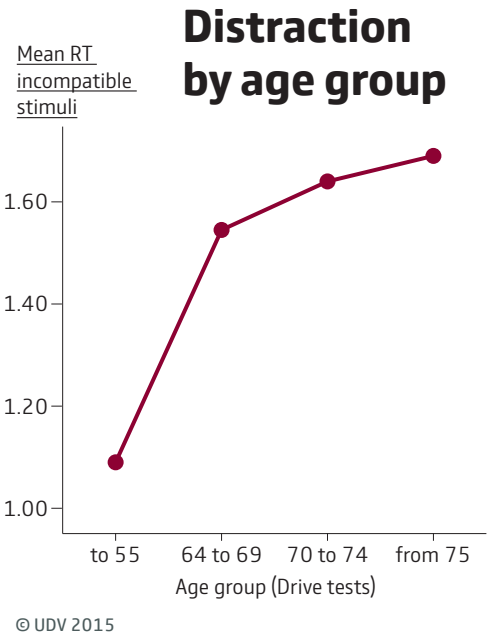
Table 3 · **Differences in psychophysiological test performance by age group (study 1 and 2)**

Variable	Age group difference		
	Study 1	Study 2	Description
Sensory performance			
Visual acuity	(0,1)>(2,3)	0> (1,2,3)	Visus 100
Peripheral perception	0>(1,2,3)	0>(1,2,3)	Degree of visual field
Contrast vision	0>((1,2)>3)	0>(1>3)	Visus 10
Cognitive performance			
Divided attention		0<(2,3)	Mean reaction time
Selective attention	0<(2,3)	0<(2<3)	Mean reaction time
Distraction (interference, Stroop Task)	0<(1,2,3)		Mean reaction time for correct and incorrect answers
	0<1<2<3	Compatible: 0<(1,2,3)	Mean reaction time for compatible and incompatible stimuli
		Incompatible: 0<(2,3)	
Distraction (inhibition, Go-NoGo Task)	0<(1,2)		Share of incorrect answers
Visual Search	0<(1,2,3)	mean reaction time for target stimuli present: 0<(1,2)	% incorrect answers, mean reaction time for correct answers, mean reaction time for target stimuli present, % missed stimuli
Obtaining an overview – traffic	0>(1,2,3)	0>(1,2,3)	Test score
Motor abilities			
Responsiveness	0<(1<3)		Mean reaction time
Motility (Neck)		0>((1>)3)	Added degrees of head rotation d to the left and right
Motility (Walking)		0>2	Mean time

Development of psychophysiological fitness

Picture 4 · **Different decline shapes for sensory and cognitive functions by age group (Study 1)**





Differences in driving performance (Study 1 and Study 2)

Table 4 displays age-related differences in driving performance. Again, only these situations are included where there were statistically significant differences between age group at 5 percent level. For example at junctions 4a and 4b at the urban stretch of the test track there are significant differences in the number of shoulder checks between age groups. There are more shoulder checks in the comparison group compared to all other older age groups (group 1, 2, 3). Beyond the result in table 4 there are statistically significant but small correlations between age and speed at the interurban stretch. That means on average the older the drivers are the slower they drive. There is no relation between age and speed at the motorway.

In summary there are only few driving situations where age-related differences become apparent. This is in line with the literature where older drivers use compensation strategies to account for their impairments in real driving. From a safety perspective the lack of shoulder checks in older age groups while turning at the urban stretch and merging in/out at the motorway are critical. It might be that in the past shoulder checks were not taught as prominently as today, but it could also be that elderly car drivers avoid it due physical problems with neck rotation. Differences in speed adaptation became only apparent in demanding situations (at the interurban section) or where car drivers were already tired (i.e. return trip on motorway). Therefore we assume speed reduction as compensation strategy to reduce mental load.

In the driving simulation scenario there are somewhat more but again not all driving situations with the expected age differences. That might be also due to the restrictions creating a demanding scenario because of simulator sickness. A truly demanding scenario is certainly longer and includes more situations of different types. Thus we might only test the lower limit of older driver's performance. There are differences between age groups for unexpected events in particular.

Few driving situations with differences by age

Table 4 · **Differences in driving performance by age group (study 1 and 2)**

	Driving Situation	Age group difference	Description
Test drive (Study 1)			
4a	Turning right at a traffic light, situation 4a	0>(1,2,3)	Number of shoulder checks
4b	Turning right at a traffic light, situation 4b	0>(1,2,3)	Number of shoulder checks
11/12	Motorway	0>(1,2,3)	Number of shoulder checks
		0>(1,2,3)	Number of mirror checks while merging back in lane
Driving Simulator (Study 2)			
15	STOP sign	ANOVA Age x Sign type	Distance to the STOP sign for the first braking: Older drivers brake earlier at the clearly visible sign, but later at the masked sign.
16b	Turning left with on-coming bicyclists	0>1>2>3	Number of correct gaps
17a/b	Crossing Pedestrian	ANOVA Age x distraction	Mean speed before appearance of pedestrian: Older drivers drive faster without but slower with distraction.
17a	Crossing Pedestrian without distraction	0>(2,3)	Time to collision (TTC)

Predicting older driver's performance with psychophysical tests

Table 5 presents the results for the prediction of driving performance with age and psychophysical variables as predictors in stepwise multiple regressions. Again, only these situations are included where there are statistically significant predictions. For example, at the inter-urban stretch number 6 higher reaction times in the visual search test where the target was present predicted lower mean speed. That could be interpreted as adequate speed adaptation according to one own ability. The prediction of driving situation 4a by age outweighing all other predictors show that sometimes age can be a relevant indicator. The prediction of driving situation 17a/b by visual acuity should be interpreted with caution. The pedestrian stepped onto the lane from the left. Therefore one would expect peripheral perception as relevant indicator. However to avoid simulator sickness the driving simulation was reduced to one middle screen. No peripheral screens were used. Therefore, drivers may recognise the pedestrian only in the foveal area instead of the peripheral one in real traffic or a three-screen simulation.

Low predictive power of psychophysical fitness

Table 5 · **Prediction of driving performance with psychophysiological indicators (study 1 and 2)**

	Driving situation (DV)	Psychophysical Tests (IV)	Description
Test drive (Study 1)			
1a	Junctions with a Give way sign and crossing of a priority street: looking at the right and left side	Adventurousness and Need for excitement (IVPE)	Person with low scores in adventurousness and need for excitement looks more often only to the left compared to person with high scores
1	Between situation 1a and 1b: mean speed	Concentration, Responsiveness	The longer the reaction times in concentration and responsiveness tests the lower the lower mean speed
2b	Junctions with left yields to the right: Eye movements only to the left while turning left	Selective attention	The shorter the reaction time in UFOV test the more eye movements only to the left
4a	Turning right at a traffic light: Shoulder check	Age	The older people are the less shoulder checks they do
6	Interurban stretch: mean speed	Visual search (if target was present)	The higher the reaction time in the visual search test the lower the mean speed
8	Interurban stretch: mean speed	Selective attention	The shorter the reaction time in selective attention the higher the mean speed
	Motorways stretch: mean speed	Peripheral perception	The larger the visual field the higher the means speed
Driving simulator (Study 2)			
15	Masked STOP Sign: Brake reaction time	Motility (Neck)	The larger the neck rotation the earlier drivers brake
17a/b	Crossing Pedestrian with and without distraction: time to collision	Visual acuity	The higher the visus 100 the earlier drivers recognise the pedestrian and brake
18b	Veering out taxi: Brake reaction time (with distraction)	Visual search	The shorter the reaction time in the visual search test for target stimuli the longer the brake reaction time towards the taxi while the driver is distracted

In summary only few driving situations were predicted by the various predictors at all. Across these situations predictors were not consistent. Furthermore, it is interesting that even though psychophysical predictors explain only little variance it outweighs the influence of age as predictor in most cases.

Discussion and conclusions

The two studies presented here investigate the relation between older car driver's psychophysical fitness and their driving performance. In Germany there is the ongoing debate about the introduction of an age-based population screening given the well-documented problems of elderly drivers, e.g. at complex junctions. Altogether 232 drivers completed several psychophysical tests and drove a test drive in real traffic or in a driving simulator respectively. Thus the results and conclusions are based on a large multi-method database.

While there are considerable age-related differences in psychophysical fitness in line with the literature there are only few driving situations with differences between age groups. Again this is in line with the literature where compensation strategies of older car drivers are documented [8]. In the driving simulation there are somewhat more situations with age-related differences as we attempted to test the limits of older drivers. However, due to simulator sickness testing the limits of older car drivers in a driving simulation is severely limited. Therefore, the simulation scenario and the results represent the lower limit of elderly car drivers. That also illustrates that a driving simulator cannot be recommended as large scale testing or training tool for elderly car drivers.

Predicting driving performance with psychophysical tests was only partially successful. No psychophysical test was able to consistently predict driving performance across driving situations. The same holds true for age as indicator. However, psychophysical tests outweigh the impact of age in most cases. Selective attention, visual search and by trend peripheral perception contributes to more than one prediction. They seem to be especially relevant.

In summary the results do not justify a mandatory driver population screening with neither age nor psychophysical tests as valid indicators [9]. We argue that older drivers do need support to maintain a safe driving performance. There should be an assessment of their psychophysical fitness on an individual level followed by tailor-made advices on how to maintain a safe driving performance or to compensate for age-related deteriorations. This would also better account for the large variance of abilities and driving performances of elderly compared to an age-based population screening.

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