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Simulated car driving and its association with cognitive abilities in patients with schizophrenia

Anselm B.M. Fuermaier [a,*,1], Dafne Piersma [a,1], Rafaele J.C. Huntjens [b], Dick de Waard [a], Celina Westermann [c], Magdalena Bossert [c], Klaus W. Lange [d], Matthias Weisbrod [e,f], Richard Bruggeman [a], Steffen Aschenbrenner [c], Oliver Tucha [a]

[a] Department of Clinical and Developmental Neuropsychology, University of Groningen, Groningen, the Netherlands
[b] Department of Clinical Psychology and Experimental Psychopathology, University of Groningen, Groningen, the Netherlands
[c] Department of Clinical Psychology and Neuropsychology, SRH Clinic Karlsbad-Langensteinbach, Karlsbad, Germany
[d] Department of Experimental Psychology, University of Regensburg, Regensburg, Germany
[e] Department of Psychiatry and Psychotherapy, SRH Clinic Karlsbad-Langensteinbach, Karlsbad, Germany
[f] Department of General Psychiatry, Center of Psychosocial Medicine, University of Heidelberg, Heidelberg, Germany

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ABSTRACT

Objectives: Patients with schizophrenia commonly suffer from impairments in various aspects of cognition. These deficits were shown to have detrimental effects on daily life functioning and might also impair car driving. This study is the first to examine driving behaviour of patients with schizophrenia using an advanced driving simulator, and to explore the role of cognitive abilities of people with schizophrenia for driving.
Methods: Non-acute patients with schizophrenia (n = 31) and healthy comparison participants (n = 31) performed a comprehensive neuropsychological assessment and driving simulator rides. Neuropsychological and driving performances were compared between groups. Moreover, associations were explored between cognitive functions and driving behaviour in the entire group.
Results: Patients with schizophrenia revealed impairments in multiple aspects of cognition. In the driving simulator, patients with schizophrenia showed no indication of deviant driving in terms of number of collisions or reacting to critical situations, and even showed better lane control compared to healthy individuals. However, patients with schizophrenia drove significantly slower than healthy individuals, and caused more hindrance to the car behind while merging on the motorway. Slower driving was associated with lower test scores on attention and processing speed. Hindering the car behind was associated with test performance on planning and inhibition.
Conclusions: It is concluded that driving of patients with schizophrenia is characterized by a relatively slow speed, and can also be impaired in certain aspects, i.e. hindering a car behind while merging. Cognitive functions are crucial for driving, and should be target of treatment.

1. Introduction

Cognitive impairments in processing speed, attention, executive control functions, and memory have been well documented as a core feature of schizophrenia (Elvevåg and Goldberg, 2000; Green et al., 2000; Heinrichs and Zakzanis, 1998; Ojeda et al., 2008). They are associated with reduced quality of life, functional disability and poor prognosis (Alptekin et al., 2005; Green, 1996; Green et al., 2000, 2004). Driving is an important activity of daily living that is related to successful occupational functioning, social participation and well-being (Chihuri et al., 2016). In patients with schizophrenia, driving may contribute to feelings of self-esteem, independence and lower levels of self-stigmatization (Gerlinger et al., 2013; Livingston and Boyd, 2010; Oxley and Whelan, 2008). However, driving performance is likely to be affected in patients with schizophrenia, given that driving is a complex task that requires an effective interplay between various behavioural, cognitive, perceptual and motor functions (Anstey et al., 2005; Fuller, 2005; Mathias and Lucas, 2009).

Nevertheless, research on driving with schizophrenia is scarce (Lipskaya-Velikovsky et al., 2013; Segmiller et al., 2017). There is only a limited number of studies on small clinical samples suggesting that patients with schizophrenia may display adverse driving performance and an increased accident risk compared to healthy individuals (Edlund et al., 1989; St. Germain et al., 2005; Wylie et al., 1993). Two studies in this

* Corresponding author at: Department of Clinical and Developmental Neuropsychology, University of Groningen, Grote Kruisstraat 2/1, 9712 TS Groningen, the Netherlands.
E-mail address: a.b.m.fuermaier@rug.nl (A.B.M. Fuermaier).
[1] To be considered as joint first authors.

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field used driving simulation to explore driving behaviour of patients with schizophrenia. In a simulated driving task administered on a desktop computer with a steering wheel and pedals, 22 patients with schizophrenia showed poorer lateral control and a slower brake reaction time when traffic lights turned red in comparison to 16 healthy participants (Wylie et al., 1993). In another driving simulator study run on a desktop computer, poorer lateral control and a slower driving speed was reported in 12 patients with schizophrenia as compared to 25 healthy participants (St. Germain et al., 2005). The driving impairments were discussed to may have been caused by positive and negative symptoms, as well as cognitive dysfunction. An alternative explanation would be that patients with schizophrenia drive slower to compensate for and adapt to cognitive impairments (Fuller, 2005), although this was not sufficient to normalize their driving performance (St. Germain et al., 2005). Moreover, antipsychotic medications may impair psychomotor functions and driving performance of patients with schizophrenia (Brunnauer et al., 2009; Kagerer et al., 2003; Soyka et al., 2005; Wylie et al., 1993).

So far, limited research has been performed to investigate driving behaviour of patients with schizophrenia, using relatively small samples, and dated driving simulator techniques that may resemble real life driving less adequately. Moreover, most studies on driving of patients with schizophrenia focused on either cognition, or driving behaviour (or medication) which does not allow investigating associations between cognition and driving. Brunnauer et al. (2009) found significant associations between performance on psychomotor tests and collisions in a driving simulator in patients with schizophrenia, but reported no other measures of driving behaviour.

In the present study, non-acute patients with schizophrenia and healthy participants completed neuropsychological tests as well as driving simulator rides. The aim was to characterize driving behaviour of patients with schizophrenia and to explore the role of cognitive abilities for driving. We expected patients with schizophrenia to perform worse than healthy individuals on neuropsychological tests for processing speed, attention, and working memory. Furthermore, we expected patients with schizophrenia to show adverse driving behaviour compared to healthy individuals, in particular in traffic situations that require fast reactions and intact attention control, such as at traffic lights, manoeuvres of other vehicles, or during merging. Finally, given the important role of cognitive abilities for intact driving, we expected to find a clear association between cognitive deficits and adverse driving in the simulator.

2. Materials and methods

2.1. Participants

2.1.1. Patients with schizophrenia

Thirty-three patients with schizophrenia took part in the present study. Two patients could not complete the driving simulation due to simulator sickness and were therefore excluded. Data of 31 patients with schizophrenia entered data analysis (Table 1). All patients indicated that they have obtained a driver license. The patients were all diagnosed with schizophrenia according to diagnostic criteria as outlined in the Diagnostic and Statistical Manual of Mental Disorders, 4th Edition (DSM-IV; American Psychological Association, 2000). Diagnostic status was supported by the Mini International Neuropsychiatric Interview (*MINI*; Sheehan et al., 1998). In this group, 30 patients were diagnosed with paranoid schizophrenia and one patient with undifferentiated schizophrenia. Seven patients had a secondary diagnosis, including psychoactive substance use disorders (but no abuse in the previous three months, n = 5), major depressive disorder (n = 1) and posttraumatic stress disorder (n = 1). The patient with posttraumatic stress disorder was additionally diagnosed with paranoid personality disorder. All patients with schizophrenia were currently treated with individually tailored doses of one or more types of psychoactive medications, including antipsychotics (n = 30), antidepressants (n = 8) and anticholinergics (n = 5). The mean haloperidol equivalent dose of antipsychotics was 8.7 mg (SD = 5.3 mg) per day as calculated based on international consensus recommendations (Gardner and O'Donnell, 2010). All patients with schizophrenia were non-acute at the time of their assessment and were invited to take part in the study if no item depicting positive symptoms of the Positive And Negative Syndrome Scale (*PANSS*; Kay et al., 1987) was higher than 5. Patients with schizophrenia obtained mean PANSS scores of 9.5 (SD = 2.7) for positive symptoms, 12.7 (SD = 4.8) for negative symptoms and 23.0 (SD = 4.2) for general psychopathology.

2.1.2. Healthy participants

Forty-eight participants were recruited from the local community and were considered for inclusion in the healthy comparison group. The community sample was screened for psychiatric disorders by self-report (presence of psychiatric or neurological illness), the MINI, and the Brief-Symptom-Checklist (*BSCL*; Franke, 2016). All individuals of the community reported that they have obtained a driver license. None of participants indicated to suffer from a current psychiatric disorder which was confirmed by the results of the MINI in each case. However, five individuals had to be excluded from further consideration because of current use of antidepressants (n = 1), neurological illness (n = 1), or very high scores (T > 69 indicating scores of 2 standard deviations or more above the mean) on at least one subscore of the BSCL (n = 3). From the remaining 43 healthy participants, 31 participants were selected based on age and sex in order to obtain a well matched comparison group to the patients with schizophrenia with similar characteristics (Table 1). For driving experience, not all participants provided a complete and/or plausible self-report, therefore these estimations were based on a slightly smaller sample.

Table 1
Characteristics of the participants.

Characteristic	Group		
	Healthy (n = 31)	Schizophrenia (n = 31)	p value (df)
Age, mean (SD), y	30.2 (8.1)	29.9 (7.9)	0.875[a] (60)
Male sex, no. (%)	16 (51.6%)	22 (71.0%)	0.192[b] (1)
Education, mean of 5 stages (SD)	3.6 (0.7)	2.9 (1.0)	0.001*,[a] (60)
IQ MWT-B, mean (SD)	106.9 (11.7)	100.5 (11.4)	0.034*,[a] (60)
BDI II, mean (SD)	4.1 (4.3)	12.6 (9.5)	<0.001*,[a] (60)
Driving experience, mean (SD), y	12.5 (7.9)	10.1 (6.1)	0.205[a] (57)
Driving experience, mean (SD), km	162,950 (155,410)	92,740 (136,290)	0.086[a] (51)
Car accident in past year, no. (%)	4 (13.3%)	4 (12.9%)	0.261[c] (2)
Traffic fine in past year, no. (%)	9 (30.0%)	6 (19.4%)	0.300[c] (2)

Statistical significance ($p < 0.05$) is indicated by *.
Abbreviations: Healthy, healthy comparison group; Schizophrenia, patients with schizophrenia; MWT-B, Multiple Choice Vocabulary Test B; BDI II, Beck Depression Inventory 2 (range 0–63).
[a] *t*-Test.
[b] Fisher's exact test.
[c] χ^2 test.

2.2. Measures

2.2.1. Interviews and questionnaires

The *MINI* (Sheehan et al., 1998) is a structured interview addressing questions about the presence of psychiatric symptoms. The *BSCL* (Franke, 2016) was completed by healthy participants only to exclude healthy participants reporting high levels of psychiatric symptoms. The *PANSS* (Kay et al., 1987) was administered to patients with schizophrenia to assess the severity of positive and negative symptoms as well as general psychopathology. A *driving questionnaire* (short version of the driving profile of Piersma et al., 2016) was used to obtain information about driving experience, car accidents and traffic fines. The *Beck Depression Inventory 2* (*BDI II*; Beck et al., 1996) was included to assess depressive symptoms.

2.2.2. Neuropsychological assessment

Premorbid intelligence was estimated with the *Multiple Choice Vocabulary Test B* (*MWT-B*; Lehrl, 1995, 2005). Neuropsychological functions were measured with six tests from the Vienna Test System (VTS; Schuhfried, 2013). These tests were selected as they represent different aspects of cognition that may be relevant for driving and were shown to be sensitive for the identification of cognitive impairments of patients with psychiatric conditions. Five tests from the *Cognitive Basic Testing battery* (*COGBAT*; Aschenbrenner et al., 2012) were administered to assess various aspects of cognition, i.e. divided attention (*Perception and Attention Functions – Divided Attention*; *WAFG*), working memory (*N-back*; *NBV*), inhibition (*INHIB*; *Go-NoGo*), processing speed and flexibility (*Trail Making Test*; *TMT*), and planning (*Tower of London*; *ToL*). Selective attention was assessed with the *Perception and Attention Functions – Selective Attention* (*WAFS*; Sturm, 2011). Additionally, the *Hazard Perception Test* (*HPT*; Piersma et al., 2017; Vlakveld, 2014) was performed. The HPT requires timely planning and decision making in an applied context of driving situations.

2.2.3. Driving simulator rides

A fixed-base Jentig50 driving simulator of ST Software was used consisting of an open cabin mock-up. Participants had a 200° view on the road on three 50 in. LED screens. The scenario was programmed with scripting language StScenario (ST Software) and simulated traffic was able to adapt to the behaviour of the participant (van Winsum and van Wolffelaar, 1993).

The driving simulation consisted of five driving simulator rides, which represent typical scenarios of everyday driving and which have been shown to be sensitive to reveal abnormal driving behaviour of participants with cognitive impairments (Piersma et al., 2016). In the first ride (Fixed Speed), participants only had to steer on a slightly winding road. The speed was controlled by the simulator and increased stepwise from 50 to 100 km/h (31 to 62 mph). Standard deviation of the lateral position (SDLP, i.e. swerving) was measured when the speed was 100 km/h. In the second ride (Free Speed), participants were driving on the same slightly winding road, but this time they had to control their own speed. There were no speed limits in this ride. At first, they were asked to drive at a speed that was comfortable for them, but halfway the ride they were asked to drive as if they were in a hurry. Both their speed and SDLP were measured while driving in a hurry. In the third ride (Intersections), participants encountered six intersections with different priority regulations. In addition, a car suddenly pulled out from a lay-by in front of the participant. The brake reaction time in response to the car that pulled out was measured. Moreover, the minimum speed when approaching an intersection was measured at three intersections where the participant had to give way. Mean speeds were measured at two parts with a speed limit of 60 km/h and two parts with a speed limit of 80 km/h. From these data, the mean deviation from the speed limit was calculated. Furthermore, the brake reaction time was measured when traffic lights turned amber. Lastly, the number of collisions was counted. The fourth ride (second intersections ride) was exactly the same as the third ride. In the fifth and final ride (Merging), participants merged on the motorway. The speed while merging was measured, as well as the deceleration of the car behind and the time headway to the car in front.

2.3. Procedure

Patients with schizophrenia were assessed at the inpatient psychiatric hospital of the SRH Clinic Karlsbad-Langensteinbach, Germany. Healthy participants were recruited from the local community and assessed at a laboratory of the University of Regensburg, Germany. Assessments were performed by trained psychology students (healthy individuals) or trained psychologists working in the clinical field (patients with schizophrenia). All participants took part in this study on a voluntary basis and were not paid for participation. Written informed consents were obtained in advance. Interviews and questionnaires ($\pm$ 1.5 h), neuropsychological tests ($\pm$1.5 h), and the driving simulator ride ($\pm$0.5 h) were administered and performed on separate days (patients with schizophrenia) or were separated by breaks (healthy individuals) in order to avoid effects of fatigue. Ethical approval was obtained from the medical ethical committee of the University of Heidelberg, Germany.

2.4. Data analysis

2.4.1. Missing data

Due to technical errors, data of the first intersections ride were missing for 15 patients with schizophrenia and one healthy participant, therefore this ride was not considered for data analysis. For one patient with schizophrenia, the number of collisions in the second intersections ride was missing and could not be retrieved because of a technical issue. Five patients with schizophrenia and one healthy participant merged on the motorway after all cars had passed, therefore the values for the deceleration of the rear car were missing in these cases. These missing values were imputed using an imputation model (including all complete variables of the driving simulator of the respective group) that was estimated by maximum likelihood (ML).

2.4.2. Statistical analyses

Because assumptions for parametric testing (e.g. normality) were violated in several variables, the present data were analysed using non-parametric statistics. Patients with schizophrenia and healthy participants were compared on neuropsychological test performance and simulated driving performance using Mann-Whitney *U* tests. Alpha level was set to 0.01 for all group comparisons in order to control for type-1 error inflation in multiple testing. Furthermore, interpretations were largely based on effect sizes which are not affected by problems of multiple testing. Effect sizes were indicated by Cohen's *r* and were classified into negligible effects ($r < 0.1$), small effects ($0.1 < r < 0.3$), medium effects ($0.3 < r < 0.5$) and large effects ($r > 0.5$) (Cohen, 1988). The associations between cognitive performance and simulated driving were explored by Spearman rank correlations between those variables of the neuropsychological tests and simulator rides that differed significantly between groups. If several variables of the driving simulator rides differed significantly between groups that represent a similar type of information (e.g. speed of driving), then these variables were averaged by calculating the mean of z-transformed variable scores.

3. Results

3.1. Group comparisons on neuropsychological assessment

Patients with schizophrenia showed significantly decreased performance in the tests for divided attention (WAFG), working memory (N-back), inhibition (Go-NoGo), planning (ToL) and hazard perception

Table 2
Comparison of the healthy comparison group with patients with schizophrenia on neuropsychological tests.

Neuropsychological tests	Healthy (n = 31)	Schizophrenia (n = 31)	Z	p[a]	ES[b]
Selective attention (WAFS)					
Logarithmic response time	354 ± 74	378 ± 95	−1.0	0.317	0.13
Logarithmic SD of response time	1.2 ± 0.1	1.3 ± 0.4	−1.0	0.331	0.12
Omission errors	0.1 ± 0.2	0.3 ± 0.7	−1.9	0.064	0.24
Divided attention (WAFG)					
Omission errors	2.8 ± 3.2	5.8 ± 4.6[c]	−2.7	0.007*	0.35
Working memory (N-Back)					
Correct responses	13.4 ± 1.7	10.4 ± 3.5	−3.6	<0.001*	0.48
Inhibition (Go-NoGo)					
Commission errors	3.8 ± 2.8	10.1 ± 8.9	−3.4	0.001*	0.43
Processing speed and flexibility (TMT)					
Time TMT A (s)	16.3 ± 3.4	20.3 ± 5.0	−3.3	0.001*	0.42
Time TMT B - Time TMT A (s)	9.2 ± 7.6	12.9 ± 8.5	−1.6	0.099	0.21
Planning (ToL)					
Planning ability	17.4 ± 2.8	11.9 ± 3.8	−5.0	<0.001*	0.64
Hazard perception (HPT)					
Response time (s)	4.4 ± 0.7	4.0 ± 0.7[d]	−1.8	0.071	0.23
Correct responses	19.2 ± 1.9	17.2 ± 2.5[d]	−2.9	0.003*	0.37

Abbreviations: Healthy; healthy comparison group; Schizophrenia, patients with schizophrenia; WAFS, selective attention test; SD, standard deviation; WAFG, divided attention test; TMT, Trail Making Test; ToL, Tower of London; HPT, Hazard Perception Test.
[a] Statistical significance ($p < 0.01$) is indicated by *.
[b] Effect size (ES) is indicated by Cohen's *r*.
[c] For 29 out of 31 patients with schizophrenia.
[d] For 30 out of 31 patients with schizophrenia.

(HPT) compared to healthy comparison participants (Table 2). Patients with schizophrenia also needed significantly more time to complete TMT A than healthy comparison participants. The effects were of medium to large size. No significant differences between groups were obtained in the test for selective attention (WAFS), in cognitive flexibility (TMT B – TMT A), as well in the response time of the HPT.

3.2. Group comparisons on simulated driving

Patients with schizophrenia showed driving behaviour comparable with healthy participants in several variables (Table 3). However, when driving in a hurry, patients with schizophrenia drove significantly slower with a significantly smaller SDLP than healthy comparison participants. Moreover, the third intersection where participants have to give way was approached significantly slower by the patients with schizophrenia than the healthy comparison participants. Similarly, patients with schizophrenia were driving on average 5 km/h below the speed limit which was significantly different from healthy comparison participants who were driving with an average speed that was very close to the speed limit. Additionally, the rear car had to decelerate significantly more after patients with schizophrenia merged on the motorway compared to healthy comparison participants. Overall, the largest effects ($r > 0.50$) were found on two speed variables (Speed in hurry, Deviation from speed limit) where patients with schizophrenia were driving at a slower speed than healthy comparison participants. Medium effects were found on the minimum speed at the third intersection, SDLP in hurry and deceleration of the rear car at merging.

Table 3
Comparison of the healthy comparison group with patients with schizophrenia on simulated driving performance.

Driving simulator rides	Healthy (n = 31)	Schizophrenia (n = 31)	Z	p[a]	ES[b]
Fixed Speed					
SDLP at 100 km/h (cm)	29.0 ± 9.7	28.6 ± 27.0	−1.9	0.053	0.25
Free Speed (no speed limits)					
Speed in hurry (km/h)	111.5 ± 8.6	95.4 ± 15.0	−4.5	<0.001*	0.57
SDLP in hurry (cm)	29.9 ± 7.9	24.5 ± 8.6	−2.9	0.004*	0.36
Intersections					
Minimum speed Int 1 (km/h)	3.8 ± 2.5	5.2 ± 13.8	−1.4	0.157	0.18
Minimum speed Int 2 (km/h)	0.0 ± 0.0	0.2 ± 0.9	−1.0	0.317	0.13
Minimum speed Int 3 (km/h)	9.0 ± 17.3	1.7 ± 2.6	−3.0	0.003*	0.38
Dev from speed limit (km/h)	0.2 ± 4.5	−5.5 ± 5.9	−4.3	<0.001*	0.55
RT Traffic lights (sec)	1.2 ± 1.1	1.3 ± 0.8	−1.2	0.229	0.15
RT Braking for car that pulls out (sec)	1.3 ± 0.3	1.4 ± 0.5	−0.2	0.871	0.02
Number of collisions	2	0	−1.5	0.147	0.18
Merging					
Speed while merging (km/h)	99.3 ± 11.2	92.6 ± 14.4	−2.0	0.048	0.25
Deceleration rear car (km/h)	−0.02 ± 0.09	−0.56 ± 1.11	−2.7	0.008*	0.34
Time headway merging (sec)	1.17 ± 0.44	1.19 ± 0.59	−0.0	0.977	0.00

Abbreviations: Healthy; healthy comparison group; Schizophrenia, patients with schizophrenia; SDLP, standard deviation of lateral position; Int, intersection with need to give right of way; Dev, deviation; RT, reaction time.
[a] Statistical significance ($p < 0.01$) is indicated by *.
[b] Effect size (ES) is indicated by Cohen's *r*.

Table 4
Spearman rank correlations between variables of simulated driving performance and neuropsychological assessment.

Spearman rank correlations	Speed (averaged)	SDLP in hurry	Deceleration rear car
Divided attention (WAFG)			
Omission errors	−0.385**	−0.217	−0.162
Working memory (N-Back)			
Correct responses	0.422**	0.147	0.235
Inhibition (Go-NoGo)			
Commission errors	0.365**	−0.131	−0.265*
Processing speed (TMT)			
Time TMT A (s)	−0.540**	−0.128	−0.240
Planning (ToL)			
Planning ability	0.324*	0.142	0.297*
Hazard perception (HPT)			
Correct responses	0.287*	0.054	0.163

Statistical significance is indicated by * ($p < 0.05$) and ** ($p < 0.01$).
Abbreviations: Speed (averaged), z-standardized averaged score of three speed variables at driving; SDLP in hurry, standard deviation of the lateral position while driving in a hurry; Deceleration rear car, deceleration of the rear car after merging on the motorway; WAFG, divided attention test; TMT, Trail Making Test; ToL, Tower of London; HPT, Hazard Perception Test.

3.3. Associations between neuropsychological test performance and simulated driving

For the purpose of correlational analysis, the three speed variables which differed significantly between patients with schizophrenia and healthy comparison participants (Speed in hurry, Minimum speed at intersection 3, Deviation from speed limit) were z-standardized based on the scores of healthy comparison participants and averaged into one variable representing behaviour on speed related variables. Furthermore, SDLP when driving in hurry and the deceleration of the rear car after merging were considered for this analysis as these also differed significantly between both groups. On the basis of the entire sample ($n = 62$), the three driving simulator variables were correlated with the six neuropsychological test scores that differed significantly between patients with schizophrenia and healthy comparison participants (Table 4). The averaged speed was strongly correlated with the time to complete TMT A. Moreover, the averaged speed moderately correlated with omission errors in WAFG, correct responses in the N-back and commission errors in the Go-NoGo. For SDLP in hurry, no significant correlations were found whereas the deceleration of the rear car was weakly correlated with results on the Go-NoGo and the ToL.

4. Discussion

Compared to healthy individuals, patients with schizophrenia showed similar and unimpaired behaviour in many aspects of simulated and real life driving. This is evidenced by comparable numbers of collisions and traffic fines in the past year of real life driving, although it must be noted that this comparison is likely confounded by the fact that inpatients with schizophrenia might have had less occasions to drive in the previous period. However, no significant differences between groups were also observed in several aspects of simulated driving, such as number of collisions, reaction times in critical situations (e.g. at a traffic light, or when a car suddenly pulls out), as well as the speed and time headway when merging.

Remarkably, patients with schizophrenia drove slower than the healthy comparison group, both in general (mean speed) and in several specific driving situations (when in a hurry and when approaching an intersection). Slowed down driving of patients with schizophrenia appears to be a robust finding as also St. Germain et al. (2005) found this in their driving simulation study. In the present study, slow driving was moderately associated to poorer performance in divided attention, working memory, and inhibition, and strongly associated to slower processing speed. The strong association between processing speed and driving speed is in correspondence with the literature implicating that slowed processing speed is central to the functional outcome in patients with schizophrenia (Dickinson et al., 2007; Ojeda et al., 2008, 2012). A slower processing speed could result in unintentional slow driving, however, it can also represent deliberate compensatory behaviour to take more time to process the traffic environment. As Fuller (2005) argued, reducing driving speed is a straightforward way of reducing the task difficulty in driving, which demonstrates the importance of behavioural adaptation for driving. In most traffic conditions this is a useful compensation technique to create more time to respond (Brundell-Freij and Ericsson, 2005), but it may be insufficient in more demanding traffic situations (e.g. when having two driving tasks simultaneously) (de Waard et al., 2009; Dotzauer et al., 2015). Even though slow driving is not directly causing crashes, slow driving may impede the traffic flow and stimulate dangerous overtaking manoeuvres of other drivers.

Notably, patients with schizophrenia showed better lane control (a smaller SDLP) at driving in hurry than healthy participants. This may indicate that the slower driving speed of patients with schizophrenia when driving in a hurry results in less swerving compared with healthy comparison participants, which could be seen as an example of successful compensation. However, in the present study, the rear car decelerated more when patients with schizophrenia merged on the motorway than when healthy comparison participants did. This difference cannot be attributed entirely to the slower driving speed of patients. Patients were actually driving at a speed comparable with the driving speed of other traffic on the right hand lane of the motorway (which was 90 km/h; 56 mph). Despite an appropriate driving speed, several patients with schizophrenia were hindering the car behind them when merging on the motorway, possibly because they did not position their car ideally between the car in front and the car behind. The deceleration of the rear car was associated with a worse performance on tests for inhibition and planning, which suggests that impairments in inhibition and planning may lead to having difficulty with timing the merging manoeuvre. It should be noted that not all patients with schizophrenia hindered the car behind when merging, and the average deceleration of −0.56 km/h at a speed of 90 km/h is only modest.

The slower brake reaction times displayed by the patients with schizophrenia in the study of Wylie et al. (1993) were not found in the current study. This discrepancy might be explained by the motor impairments of the patients with schizophrenia in the study of Wylie et al. (1993), as the authors put parkinsonian motor impairments forward as the likely main mechanism by which antipsychotic medications may impair driving and report a significant correlation between parkinsonism and brake reaction times in their trial sessions. Motor impairments may have been less pronounced in the present sample of patients with schizophrenia because of the use of atypical antipsychotic medications (Gallhofer et al., 1996; Kagerer et al., 2003; Soyka et al., 2005). The finding that patients with schizophrenia showed less swerving in the hurry condition than healthy participants also contrasts with the findings of previous studies in which lane tracking was compromised in patients with schizophrenia (St. Germain et al., 2005; Wylie et al., 1993). The discrepancy between the previous studies and the current study cannot be explained by the implementation of driving in a hurry, because patients with schizophrenia were also driving slower and showed less swerving than healthy comparison participants when driving at a speed of their own choice in the present study.

5. Limitations and future directions

The present study has several limitations. First, even though cognition is assumed to be important for safe driving, the present data are correlational in nature and do not allow the conclusion that the observed cognitive deficits result in altered or impaired driving of patients with schizophrenia. Standard deviations in the group of patients with

schizophrenia (Tables 2–3) were often large indicating heterogeneity across patients, and possibly normal performance in a subsample, raising the question whether also other variables than cognitive functions (such as psychopathology or driving experience) may explain driving performance. Taking into consideration limitations with regard to the sample size and not available psychopathological data in the healthy comparison group, an explorative data analysis was performed (see supplementary file) that showed that neither positive and negative symptom scores (PANSS) nor medication use (haloperidol equivalent dose) was significantly associated to critical aspects of driving performance in patients with schizophrenia. In the entire sample (patients with schizophrenia and healthy comparison participants), depressive symptoms (BDI scores) but not driving experience was demonstrated to be significantly associated to driving (see supplementary file for presentation of data analysis). Future research on larger samples of patients with schizophrenia could help to elucidate which aspects (e.g. type and severity of symptoms, medication use, driving experience) are most relevant for different aspects of driving.

Furthermore, it must be noted that patients with schizophrenia differed from the healthy comparison participants in several characteristics which might compromise the comparability of the two samples. For example, patients with schizophrenia had significantly higher scores on depressive symptoms which could have contributed to the impaired neuropsychological and simulated driving performance. Depressive symptom severity has been related to impaired cognitive performance in various domains including processing speed (McDermott and Ebmeier, 2009). Moreover, a trend was found for patients with schizophrenia to have driven less distance than healthy comparison participants consistent with results from Steinert et al. (2015).

Finally, it must also be noted that simulated driving performance does not perfectly mirror real-life driving, so it is important to investigate whether driving behaviour found in simulated driving corresponds with on-road driving behaviour in patients with schizophrenia.

6. Conclusions and implications

Patients with schizophrenia showed different and non-optimal driving behaviour compared to healthy participants in specific but not all aspects of driving. We conclude that driving of patients with schizophrenia can be described as slower, and impaired in certain aspects (i.e. hindering a rear car when merging). Moreover, cognitive abilities as assessed with neuropsychological tests could be associated with either slow driving or hindering the car behind while merging on the motorway. In older adults, processing speed training appeared to improve everyday functioning, including driving performance (Ball et al., 2007). It therefore appears relevant to explore whether also patients with schizophrenia could benefit from processing speed training (Cassetta and Goghari, 2016; McGurk et al., 2007) to show more adequate driving. Cognitive remediation appears particularly promising as patients with schizophrenia show unimpaired behaviour in several aspects of driving and need training in selected aspects only. Compensatory strategies appear also beneficial, e.g. to drive slower in order to take more time to process the traffic situation. However, as such a compensatory strategy may be insufficient in more demanding traffic situations, a combination of cognitive remediation and compensation appears most promising. Cognitive abilities and driving skills are important targets of treatment for patients with schizophrenia, as staying mobile is crucial for social participation, feelings of self-efficacy and well-being (Marottoli et al., 2000; Oxley and Whelan, 2008), and may also contribute to the reduction of self-stigmatization (Gerlinger et al., 2013; Livingston and Boyd, 2010).

Conflict of interest statement

The authors declare no conflict of interest.

Contributors

Conceptualization: AF, DP, RH, DdW, CW, MB, KL, MW, RB, SA, OT.

Data collection and assessments: AF, CW, MB, KL.

Statistical data analyses and consultancy: AF, DP, RH, DdW, CW, MB, KL, MW, RB, SA, OT.

Interpretation of results: AF, DP, RH, DdW, CW, MB, KL, MW, RB, SA, OT.

Writing original draft, review and editing: AF, DP, RH, DdW, CW, MB, KL, MW, RB, SA, OT.

All authors contributed to and have approved the final manuscript.

Role of the funding source

The funding source has played no role in the design or performance of the study, including conceptualization, data collection and assessment, statistical analyses, data interpretation, report writing, and decision to submit results.

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Appendix A. Supplementary data analysis

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