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ORIGINAL PAPER

The Impact of HIV-Associated Neurocognitive Impairment on Driving Performance in Commercial Truck Drivers

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Abstract
Driving ability can be diminished amongst people with HIV with associated neurocognitive impairment (NCI). We explore the relationship between HIV status, NCI and driving ability in professional truck drivers. Forty male professional drivers (20 HIV-positive; mean age = 39.20 ± 7.05) completed a neuropsychological test battery, two driving simulator tasks that assessed driving ability, and a driving history and habits questionnaire. A higher proportion of HIV-positive drivers exhibited impaired overall cognitive performance ($p \leq 0.001$). Overall, drivers with NCI (defined as $z \leq 1.00$) were more likely than those without NCI to crash ($p = 0.002$). There were no significant between-group (HIV-positive versus HIV-negative) differences with regard to self-reported on-road driving events. Professional drivers with NCI, as measured on a driving simulator, are at increased risk of making driving errors under high-risk conditions compared to their neurocognitively normal counterparts. These data should inform driver health management with regard to annual medical screening and surveillance.

Keywords Cognition · Automobile driving · Truck drivers · HIV-associaited neurocognitive disorders · Occupational health

Resumen
La capacidad de conducción puede verse disminuida entre las personas con VIH con deterioro neurocognitivo asociado (neurocognitive impairment, NCI). Exploramos la relación entre la situación frente al VIH, el NCI y la capacidad de conducción en conductores profesionales de camiones. Cuarenta conductores profesionales masculinos (20 seropositivos, edad media = 39.20 ± 7.05) completaron una batería de pruebas neuropsicológicas, dos tareas de simulador de conducción que evaluaron la capacidad de conducción y un cuestionario de hábitos y antecedentes de conducción. Una mayor proporción de conductores VIH positivos exhibió un desempeño cognitivo general deficiente ($p \leq 0.001$). En general, los conductores con NCI (definido como $z \leq 1.00$) tenían más probabilidades de chocar que aquellos sin NCI ($p = 0.002$). No hubo diferencias significativas entre los grupos (VIH positivo frente a VIH negativo) con respecto a los eventos autoinformados de conducción en carretera. Los conductores profesionales con NCI, según lo medido en un simulador de conducción, tienen un mayor riesgo de cometer errores de conducción en condiciones de alto riesgo en comparación con sus homólogos neurocognitivamente normales. Estos datos deberían informar a la gestión de la salud del conductor en lo que respecta a la vigilancia y los exámenes médicos anuales.

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Introduction

Driving is a complex task that relies on intact perception, attention, tracking, choice-reaction sequential movements, judgment, and planning [1]. Hence, driving performance is often affected negatively by neurocognitive impairment (NCI) [2]. NCI is a relatively common consequence of HIV infection [3]. Although some studies have found that HIV-associated neurocognitive impairment (HNCI) in non-professional drivers may be associated with more moving violations and a higher crash rate, no previously published study has investigated whether HNCI affects the occupational performance of professional drivers [4–9]. This question is particularly pertinent because commercial driving, being ubiquitous, is a key factor in public safety [10], and vehicle crashes are a well-established cause of work related mortality among professional drivers [11].

Advances in antiretroviral therapy (ART) have resulted in people with HIV (PWH) with adequate access to care having near-normal life spans, experiencing markedly improved physical health, and therefore remaining in the workplace longer [12–14]. Nonetheless, the prevalence of HNCI remains high. In the general population, 30–50% of PWH continue to present with HNCI, albeit at markedly reduced severity than during the pre-ART era [15, 16]. Thus, it is likely many people with mild HNCI will maintain steady employment, with one study estimating the overall prevalence of HNCI in an occupational health setting to be 32% [17].

Even when mild, HNCI can have significant medical, health, and functional consequences [18, 19]. Affected individuals have poorer online shopping and banking skills [20], disrupted activities of daily living [15, 21, 22], worse adherence to medication [23, 24], weaker decision-making capabilities [25], and increased risk of mortality [16, 21, 22]. PWH with NCI are significantly more likely than those without to report job performance difficulty and to function significantly more poorly on standardized work activities [26, 27]. Furthermore, in PWH neuropsychological impairment predicts lower employability over and above medical symptoms [28].

NCI also negatively impacts driving ability [2, 4–6, 8, 9, 29–31]. A small body of research strongly suggests that, among non-professional drivers, a subset of PWH with NCI present with an overall decline in driving ability [4–9, 32]. For instance, Marcotte et al. [4] reported that (a) 29% of PWH whom they assessed gave subjective reports of declines in driving ability, and (b) neurocognitively impaired subjects were more likely than unimpaired subjects to have had a moving violation in the past year, and had a higher crash rate. On driving simulator testing, cognitively impaired PWH demonstrated greater swerving and caused significantly more crashes than those who were not impaired [4]. In a separate study that used on-road driving testing, HNCI PWH were rated as unsafe at a significantly higher rate than those who were not impaired, and made almost three times the number of navigational errors [8]. These findings may be explained by independent study findings that impairment in domains of executive function, attention [5], and processing speed [5, 9] is associated with poorer performance on simulator testing.

No published study has examined whether professional truck drivers with HIV and HNCI exhibit similar negative driving outcomes as non-professional drivers with HNCI. Professional drivers differ from non-professional drivers in that they have more driver training and driving experience. Because truck drivers are at higher risk of aquiring HIV, they may be vulnerable to critical risks that can endanger the individual driver and other road users [33–36]. Despite this increased risk for HIV, and by association NCI, occupational health management of drivers and other employees who present with NCI is under-researched and poorly understood.

The Current Study

We investigated the impact of NCI on driving simulator performance in a sample of HIV-positive professional truck drivers and matched healthy controls, positing that the former will present with higher rates of NCI, and that NCI will translate into poorer driving simulator performance.

Methods

Participants

This study is nested within a larger research program assessing the effects of HNCI on driving performance in professional drivers from SSA. Data was collected from August 2017–July 2019. We used convenience and snowball sampling to recruit 40 male professional truck drivers (20 HIV-positive, 20 HIV-negative) from occupational and primary healthcare clinics, a roadside mobile-wellness clinic for truckers, an HIV patient health management company, and various social media outlets. HIV-negative controls were matched by age and education to the first 20 HIV-positive drivers enrolled.

The parent study's inclusion criteria were: (1) employment as a professional driver for ≥ 1 year; (2) ≥ 12 h of driving per week in a professional capacity; (3) English fluency at a conversational level, minimally; and 4) possession of a valid South African professional driver's permit (PrDP). To obtain or renew this certification, drivers are required to have a biennial (or more frequently if required) medical assessment certifying that they are in good health and meet

National Road Traffic Act medical fitness requirements for professional drivers [37]. PWH were required to have been on ART for ≥ 3 months prior to enrolment in this study.

The parent study's general exclusion criteria were: (1) a history of reported non-HIV-related neurological disorder or medical disorder affecting the nervous system (e.g., stroke, epilepsy, or head injury with loss of consciousness for ≥ 30 min or hospitalization as a result); (2) the presence of an Axis I DSM disorder, except major depressive disorder (due to the high prevalence of depressive symptoms in professional drivers, we did not exclude potential participants on this criterion [38]); (3) a self-reported history of learning disability; and (4) current substance abuse or dependence assessed using the Alcohol Use Disorders Identification Test (AUDIT; cut-off score ≥ 8) and a urine toxicology screen for THC, MDMA, cocaine, opioids, amphetamines. Participants who tested positive for THC were only excluded if they used marijuana within the past 24 h or were visibly intoxicated.

Additional exclusion criterion for the control-group only was a diagnosis of diabetes (by self-report), another medical condition that is highly prevalent in professional drivers and that has independent association with NCI. Seronegative status was confirmed using an ELISA finger prick test conducted on the same day as other research assessments.

The Human Research Ethics Committee, Faculty of Health Sciences, University of Cape Town, approved this study. All participants provided informed written consent before study participation.

Measures and Procedure

Neuropsychological Testing

All participants completed a comprehensive neuropsychological assessment battery, administered by a trained psychometric technician and supervised by a clinical neuropsychologist. The battery tested these domains using these instruments: (1) Motor function: Grooved Pegboard Test (GPT); Finger Tapping Test (FTT); (2) Processing speed: Trail Making Test Part A (TMT A); Color Trails Test 1 (CTT1); Wechsler Adult Intelligence Scale—Third Revision (WAIS-III) Digit Symbol-Coding and Symbol Search subtests; (3) Attention: Paced Auditory Serial Addition Test (PASAT); WAIS-III Digit Span subtest; Wechsler Memory Scale-Third Revision (WMS-III) Spatial Span subtest; (4) Verbal fluency: category (animals, fruits and vegetables) and action fluency tests; (5) Memory: Hopkins Verbal Learning Test-Revised (HVLT-R); Brief Visuo-Spatial Memory Test-Revised (BVMT-R); and (6) Executive functioning: 64-item computerized Wisconsin Card Sorting Test (WCST); Color Trails Test 2 (CCT2).

This collection of tests, which is based on the HIV Neurobehavioral Research Center battery [3], is appropriate for use in South Africa [39]. Test administration took approximately 2.5 h.

Driving Simulations

Participants completed two interactive driving simulations using STISIM Drive software [40] on TMI Dynamics vSIMC200 hardware [41] modelled on the interior and performance of a VW Polo 1.4. The simulator has three side-by-side monitors giving 180-degree field of view. To ensure we were measuring driving performance on simulator assessments rather than ability to use the simulator, participants completed a simulator training session that included stopping at a traffic light, making an emergency stop, and negotiating turns in the face of oncoming traffic. After that training session they completed five individual training-drives to acclimate them to the driving simulator and then two assessment-drives, described below. This procedure lasted approximately 1.5 h. The driving tasks were designed to reflect real-world driving situations and known road conditions in South African urban regions (e.g. driving on the left side of the road).

The first simulation (Simulator Task 1) emulated city- and country-driving and lasted 25 min. The participant drove through built-up residential areas and on freeways while maintaining various designated speeds and appropriate lane positions. During this drive, they had to (a) make two right turns into oncoming traffic; (b) retain and accurately recall, on two occasions, instructions to press the horn at a designated point; (c) stop at an amber traffic light; (d) make an emergency stop to avoid hitting a pedestrian; and (e) enter a busy freeway from the right and subsequently cross three lanes to exit the freeway using an off-ramp on the left.

The second simulation (Simulator Task 2), a cognitive demanding divided attention task, lasted 7 min. Participants drove through a residential area at 60 km/h (37 mph), stopping at intersections and avoiding crashes with pedestrians and other cars while responding appropriately to a series of symbols (left arrow, right arrow, diamond) that appeared in the lower left and right corners of the central monitor. They had been trained to associate each symbol with either the left-turn signal, right-turn signal, or horn, and had to respond to their appearance without making driving errors.

Real-World Driving History

The self-report Driving History and Habits questionnaire (DHH) [8] collected information spanning the 12 months prior to reporting about number of traffic tickets received, number of minor and major traffic accidents, and distance travelled.

Data Management and Statistical Analyses

Deriving Outcome Variables

For the neuropsychological testing, we converted raw scores to *z*-scores using this formula:

$$z = \frac{participant's\ score - mean\ score\ of\ control\ group}{SD\ of\ control\ group}$$

The control and PWH groups were well-matched demographically, which minimized the need for any adustments to the z-scores. We then created composite *z*-scores for six pre-defined cognitive domains (Motor Function, Processing Speed, Attention, Fluency, Learning/Memory, and Executive Function) by averaging the *z*-scores of the individual outcome variables comprising each domain (see Table 1). We set the threshold for impaired performance within each domain at $z \leq 1.00$.

Finally, we calculated a Global Deficit Score (GDS) score for each participant by (a) converting each *z*-score to a *T*-score using the formula $T = 10z + 50$; (b) converting each *T*-score into a deficit score; and (c) averaging the deficit scores [42]. We classified GDS scores > 0.5 as indicating NCI [42].

Driving simulator outcomes were collected automatically by the software. Primary outcomes for Simulator Task 1 were: (i) total crashes (driving into other cars, pedestrians, and/or off the road), (ii) exceeding the speed limit indicated by road-side signs, (iii) not stopping at red traffic lights, (iv) deviation of lateral position (swerving) on the road, and (v) overspeed time (amount of time spent speeding, summed over the duration of the task). Primary outcomes for Simulator Task 2 were: (i) total crashes, (ii) exceeding the speed limit, (iii) not stopping at stop signs, and (iv) correct and incorrect responses to the divided attention task. For the divided attention task, the final score was the number of correct items (lower scores = poorer performance). We set the threshold for impaired performance on each simulator outcome variable at $z \leq 1.00$.

Statistical Analyses

As an initial step, we checked the distribution of each outcome variable individually for statistical outliers (defined as < 3 *SD* from the group mean) and non-normality. We removed the following outlying scores from analyses for these variables: *z*-Fluency (two HIV-negative driver scores), *z*-Attention (three HIV-negative driver scores), *z*-Motor (one HIV-positive driver score), GDS (three HIV-negative driver scores; Deviation of Lateral Position on Simulator Task 1 (one HIV-positive driver and two HIV-negative driver scores); Exceeding the Speed Limit on Simulator Task 1 (one HIV-negative driver score); and Overspeed Time on Simulator Task 2 (one HIV-positive driver score).

Table 1 Neuropsychological test outcome variables used to create cognitive domain composite scores

Cognitive domain	Test outcome variables within domain
Motor skills	GPT: time to completion, DH and NDH FTT: number of finger taps within designated time, DH and NDH
Processing speed	TMT-A: time to completion CTT1: time to completion WAIS-III digit symbol-coding: total completed correctly WAIS-III symbol search: total completed correctly
Attention	WMS-III spatial span forwards: total score WMS-III spatial span backwards: total score WAIS-IIII digit span forwards: total score WAIS-III digit span backwards: total score PASAT: total correct
Fluency	Animals: total number of correct words Fruits and vegetables: total number of correct words Action: total number of correct words
Learning/memory	HVLT-R: total correct across the three learning trials HVLT-R: total correct on the delayed recall trial BMVT-R: total correct across the three learning trials BVMT-R: total correct on the delayed recall trial
Executive function	CTT2: time to completion WCST: categories completed

GPT Grooved Pegboard Test, *DH* dominant hand, *NDH* non-dominant hand, *FTT* Finger Tapping Test, *TMT-A* Trail Making Test, Part A, *CTT1* Color Trails Test, Trail 1, *WAIS-III* Wechsler Abbreviated Scale of Intelligence—Third Edition, *AASS* age-adjusted scaled score, *WMS-III* Wechsler Memory Scale—Third Edition, *PASAT* Paced Auditory Serial Addition Test, *HVLT-R* Hopkins Verbal Learning Test-Revised, *BVMT-R* Brief Visuo-Spatial Memory Test-Revised, *CTT2* Color Trails Test, Trails 2, *WCST* Wisconsin Card Sorting Test

One-tailed independent-sample *t*-tests (or Mann–Whitney *U*-tests where assumptions were violated) assessed the magnitude of between-group differences with regard to sample sociodemographic characteristics and self-reported driving history, neuropsychological test performance, and driving simulator performance. Second, one-tailed Mann–Whitney *U*-tests assessed the magnitude of simulator performance differences between neurocognitively normal and neurocognitively impaired participants (regardless of HIV status), with groups defined following the criteria described above. Third, Fisher's Exact tests compared, across groups and for each neuropsychological outcome, the proportion of individuals classified as impaired ($z < -1.00$). Finally, bivariate correlational analyses using Pearson's *r* coefficient assessed the magnitude of relationships between simulator performance and real-life driving events (as reported on the DHH).

Results

Sample Characteristics

The mean age for the all male sample (reflective of professional drivers in SSA) was 39.2 ± 7.05 years and 50% had ≥ 12 years of education. Control and PWH groups were well matched in terms of age, education, employment status, driving experience, and self-reported driving history over the past 12 months (see Table 2).

In the PWH group, the nadir CD4 count was < 350 in 9 (42%) participants, between 351 and 500 in 5 participants (26%), between 500 and 1000 in 2 (11%) participants; four (21%) drivers did not know their nadir CD4 count. The mean CD4 count at study assessment was 534.07 ± 290.08 cells/mm^3 ($n = 15$). At study assessment, 12 of those 15 drivers had non-detectable viral load. The mean viral load for the other three was $4.8_{10} \pm 0.5_{10}$.

Neuropsychological Test Performance and Impairment Rates

PWH drivers performed significantly more poorly than their HIV-negative counterparts in cognitive domains Processing Speed, Attention, Learning/Memory, and Executive Function. They also had significantly higher GDS scores, indicating a greater level of overall NCI (see Table 3).

Figure 1 shows a significantly higher proportion of PWH drivers than control drivers were classed as impaired ($z \leq 1.00$) in the domains of Processing Speed ($p = 0.001$, Cramer's $V = 0.524$) and Learning/Memory ($p = 0.046$, $V = 0.329$), and in terms of overall cognitive performance as measured by the GDS ($p = 0.003$, $V = 0.460$). For all other domains, $p > 0.063$, $V < 0.300$.

Table 2 Sample sociodemographic characteristics and driving history ($N = 40$)

Variables	Group				*t*	*p*	*Cohen's d*
	HIV-negative ($n = 20$)		HIV-positive ($n = 20$)				
	M/f	*SD/%*	*M/f*	*SD/%*			
Sociodemographic characteristics							
Age (years)	39.20	7.06	39.20	7.05	0.00	1.00	0
Education (years)	10.95	1.57	11.40	1.53	−0.916	0.36	0.26
Employed full time[a]	20	100	17	85	–	0.231	0.29
Driving history							
Overall driving experience (years)	15.15	9.24	18.6	10.18	−1.11	0.274	0.35
Professional driving experience (years)	10.42	5.23	13.42	8.42	−1.32	0.196	0.43
DHH[b]							
Moving violations[c]	1.42	2.09	0.65	0.81	−1.53	0.112	0.49
Close Calls	8.00	25.26	3.68	6.59	−0.72	0.239	0.24
Total crashes	0.30	0.47	0.42	0.77	−0.60	0.554	0.19
Kilometers driven[d]	38 064	12 009–156 000	48 000 48	24 000–142 992	0.03	0.980	0.01
Self-reported crashes/million kms	8.01	17.81	5.19	13.71	0.53	0.600	0.19

DHH Driving History and Habits Questionaire

[a]Data represented are frequencies (*f*) and proportions (%). Fisher's Exact test performed. In this case, effect size = Cramer's *V*

[b]Data based on 17 HIV-positive drivers and 19 HIV-negative drivers. Driving history was collected for the past 12 months

[c]Data based on 19 PWH drivers

[d]Median and Inter Quartile Range (IQR)

Table 3 Between-group comparisons: neuropsychological test performance (N = 40)

Cognitive domain	Group				*t*	*p*	*ESE*
	HIV-negative ($n = 20$)		HIV-positive ($n = 20$)				
	M	*SD*	*M*	*SD*			
Motor function[a]	0.00	0.60	0.08	0.63	−0.41	0.344	0.13
Processing speed	−0.09	0.85	−1.20	0.70	4.50	< .0.001**	1.43
Attention[b]	−0.21	0.51	−0.73	0.57	2.87	0.004*	0.96
Fluency[c]	−0.17	0.60	−0.47	1.11	1.01	0.159	0.33
Learning/memory	0.00	0.79	−0.48	0.85	1.82	0.038*	0.58
Executive function	0.00	0.85	−0.55	0.94	1.96	0.029*	0.61
GDS[d]	0.13	0.04	0.68	0.46	−4.78	< 0.001**	1.62

Data presented are *z*-scores and statistical analyses thereof

ESE effect size estimate (Cohen's *d*), *GDS* Global Deficit Score

[a]Data from 19 HIV-positive drivers

[b]Data from 17 HIV-negative drivers

[c]Data from 18 HIV-negative drivers

[d]Data from 17 HIV-negative drivers

*$p < 0.05$, **$p < 0.001$

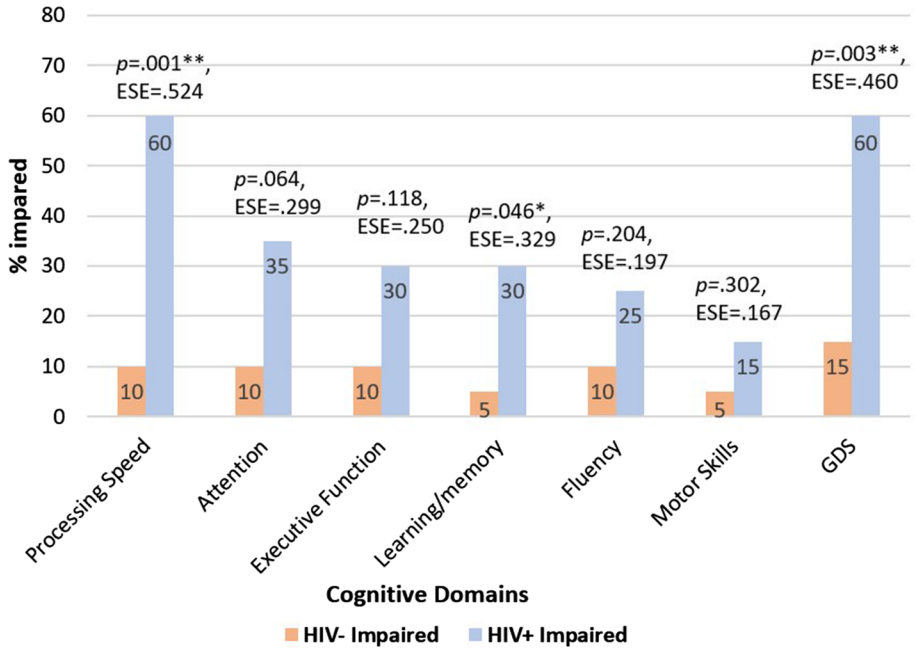

Fig. 1 Proportion of HIV-negative and HIV-positive drivers impaired within discrete cognitive domains and overall. Data presented within the bars are raw numbers. *GDS* global deficit score. [a]Data from 19 HIV-positive drivers. [b]Data from 17 HIV-negative drivers. [c]Data from 18 HIV-negative drivers. [d]Data based on 17 HIV-negative drivers. *$p < 0.05$. **$p < 0.01$

Driving Simulator Performance

PWH drivers had significantly more likely speed exceedences and a greater standard deviation of lateral position (swerving) on Simulator Task 1, with the number of crashes on Simulator Task 2 approaching significance ($p = 0.081$; see Table 4). When examining those with and without NCI, drivers classified as NCI had a significantly higher number of crashes than non-NCl drivers (see Table 5). All three significant between-group differences were associated with medium effect sizes.

Associations Between Simulator Performance and Driving History

Analyses detected no significant associations between any of the DHH variables (12-month history of traffic tickets and crashes and any of simulator outcome variable (all $rs < 0.31$, all $ps > 0.252$).

Table 4 Between-group comparisons, HIV-positive versus HIV-negative: driving simulator performance (N = 40)

Outcome variable	Group				*U*	*p*	*r*
	HIV-negative		HIV-positive				
	(*n* = 20)		(*n* = 20)				
	Median	IQR	Median	IQR			
Simulator task 1							
Total crashes	0	0–1	1	0–2	155.5	0.153	0.16
Exceeding speed limit	7	6–9	9.50	7–12	122.5	0.028*	0.31
Not stopping at red traffic lights	1	1–2	1	1–3	164.5	0.223	0.12
Deviation of lateral position[a]	3	1–4	4	3–8	111	0.012*	0.36
Overspeed time	4924	3417–5501	3722.50	55.75–5375.50	147	0.113	0.19
Simulator task 2							
Total crashes	0	0–1	1	0–1	137	0.081	0.22
Exceeding speed limit	1	0–5	1	0–4.75	174.5	0.434	00.03
Not stopping at stop sign	2	0.75–3	2	1–3	158	0.255	0.10
Overspeed time[b]	61.50	0–355.75	3.06	0–51.63	154	0.217	0.13

IQR interquartile range

[a]Data from 19 HIV-negative drivers

[b]Data from 19 HIV-positive drivers

*$p < 0.05$

Table 5 Between-group Comparisons, Neurocognitively Normal versus Neurocognitively Impaired: Driving simulator performance (N = 40)

Outcome variable	Group				*U*	*p*	*r*
	Neurocognitively normal		Neurocognitively impaired				
	(*n* = 24)		(*n* = 15)				
	Median	IQR	Median	IQR			
Simulator task 1							
Total crashes	0.5	0–1.75	1	0–2	145.00	0.850	0.17
Exceeding speed limit	7.5	6–9	10	7–12	130.00	0.146	0.23
Not stopping at red traffic lights	0	0–0	0	0–0	166.50	0.558	0.09
Deviation of lateral position[a]	3	2.25–5	3	2–11	165.50	0.670	0.07
Overspeed time	4730.50	297.14–5354.25	4765	62.52–5452	171.00	0.795	0.04
Simulator task 2[a]							
Total crashes	0	0–1	1.5	1–2	73.50	0.002*	0.50
Exceeding speed limit	1	0–3.75	3	0–5	129.00	0.222	0.20
Not stopping at stop sign	2	0.25–2	2	1–4.25	115.00	0.100	0.27
Overspeed time	0.67	0–119.50	12.56	0–249.25	136.00	0.318	0.16

One driver with NCI was removed from analysis due to missing data

IQR interquartile range

*$p < 0.05$

[a]Data based on 14 neurocognitively impaired drivers

Discussion

This study is the first to report on driving simulator performance in truck drivers with and without HIV, and to assess driving simulator performance in these truck drivers with and without NCI. We found significantly higher rates of NCI in PWH, and worse performance on simulator tasks in drivers with NCI.

Our hypothesis that higher rates of NCI would be detected in the HIV-positive group was confirmed. Using GDS ≥ 0.5 as a cut-off, significantly more HIV-positive (60%) than HIV-negative (15%) drivers were classed as being impaired.

This rate of HNCI is consistent with those previously reported in the general population [16], but is higher than previously published prevalence data (32%) of HIV-associated NCI in the workplace [43].

Regarding neuropsychological test performance, average scores of HIV-positive drivers were significantly lower than those of HIV-negative drivers overall (as measured by GDS) and in four of six cognitive domains: processing speed, attention, learning/memory, and executive function. Some previous studies suggest that poor performance on tests assessing these cognitive functions (and especially processing speed, learning, and memory) is significantly associated with on-road driving performance [2, 44]. The fact that this data pattern was not replicated in this study may be due to crashes being rare events. It may also be consistent with evidence from another set of studies indicating that mild-to-moderately deficient performance in these domains does not necessarily translate to driving impairment [45, 46]. There is, however, the risk that these mild cognitive deficits may increase in severity over time, and therefore drivers who present with any such deficit should be monitored carefully [47, 48]. Rehabilitation studies suggest that cognitive remediation training may mitigate driving risk [49].

Our hypothesis that HIV-positive drivers will have poorer performance on driving simulator tasks (perhaps because of higher NCI rates) was only partially confirmed. HIV-positive drivers scored significantly more poorly on two important simulator outcomes: maintaining lane position and keeping within the speed limit. However, our analyses detected no significant correlations between these high-risk driving practices in the simulator and real-world driving (e.g., crashes) as captured by the DHH data. This lack of association may be attributed to the small sample size, the fact that crashes are rare, though critical events and will likely be less evident in a small sample, or poor self-report regarding adverse real-world driving events. Further investigation is warranted here.

Our hypothesis that drivers with NCI will make more driving errors on simulator tasks was also only partially supported. Our analyses detected no significant differences in Simulator Task 1 performance between drivers with and without NCI. This task is representative of normal driving conditions and has a light cognitive load. This finding suggests that professional truck drivers with mild-to-moderate NCI function adequately under average driving conditions. One reason they might be able to maintain this level of occupational capability is that, because of their driving experience and practice, they may have increased 'functional reserve' compared to non-professonal drivers [50, 51]. However, on Simulator Task 2 (a more challenging task that taps into divided attention and therefore might present a larger cognitive burden), drivers with NCI were significantly more likely than those without to have a crash. This finding suggests that, under conditions of relatively high cognitive load and in a high-risk driving environment, drivers with NCI may not be able to make the necessary adjustments (e.g., pay attention to multiple stimuli and slow down at the same time) that the task demands. This may be especially true because the NCI characterize deficits related to speed of information processing. In summary, although drivers with NCI might be able to perform within the average range during routine driving tasks, they may have greater difficulty coping with more challenging or unexpected on-road scenarios. This finding highlights a need to actively screen for NCI and to manage drivers with cognitive symptoms [52].

Regarding future clinical and research directions, commercial drivers in South Africa already undergo regular health assessments because they are prone to medical conditions (e.g., HIV, diabetes) that are associated with increased driving risk (e.g. crashes) [10]. However, the role of NCI in these driving risks are poorly described and understood. As such, standard occupational health assessments required for renewal of PrDP licensing do not routinely include cognitive assessments [53, 54]; they only include proxies for health such as CD4 count, viral load, and blood sugar levels. Such biological markers are, however, poor proxies for level of cognitive functioning. Hence, in the case of HNCI and similar conditions, these assessments cannot provide reliable information about a driver's capacity for road safety nor inform future health management adequately. Note that other larger studies have shown that HIV itself is not a risk factor for impairment in driving, but that NCI is the risk factor. Again, of those with NCI, only certain persons may exhibit impaired driving [5]. Of note here too is that a diagnosis of NCI alone should not indicate automatic exclusion from driving as impairment ranges from mild to severe. NCI should therefore not be used as a sole assessment to gauge fitness to drive, but should rather be a pre-cursor to an occupational driving assessment.

Understanding the nuanced effects of NCI on driving performance will inform treatment models built on the growing consensus that routine targeted screening for NCI among PWH and others at risk of NCI is good clinical practice [55, 56]. Such screening can assist in identifying individuals with cognitive deficits on the mild to severe spectrum, will allow clinicians to establish a baseline that will facilitate longitudinal monitoring of capacity and deficit change over time, and help in the process of making judicious referrals for specialist on-road assessment [2].

Limitations

Due to truck drivers' unyielding work schedules, and fear of recrimination and stigma amongst HIV-positive drivers, this study faced difficult recruitment challenges, resulting

in a small sample size. Data should therefore be interpreted with caution. Our analysis was underpowered to examine PWH with NCI vs. those without NCI. Moreover, the outcomes may have been influenced by volunteer bias because drivers self-selected to participate. We have no way to know whether this was a representative sample (e.g., in terms of driving record) from the population of truck drivers in South Africa. Finally, we could not validate self-reported driving histories. Future research should adopt a larger and more diverse sample, investigate the impact of NCI in PWH in on-road driving situations, collect objective or collateral data regarding driving history, and examine whether certain types of interventions (e.g., cognitive remediation training (CRT; behavioral and cognitive training interventions that improve cognitive processes) [57]) might serve as protective factors in driving practices.

Conclusions

Drivers with NCI are at increased risk of impaired simulator driving performance. Early detection of HNCI is important for treating drivers with HIV adequately, planning for present and long-term preventative care of comorbid factors associated with the infection, and for managing drivers effectively [27, 55, 58]. These data build on the growing consensus that routine screening for NCI among professional drivers with conditions that predispose them to NCI is good clinical practice. Clinicians should be attentive to screening for and management of NCI in individuals employed in high-risk settings.

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