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Visuospatial and Attentional Abilities Predict Driving Simulator Performance Among Older HIV-infected Adults

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Abstract

Objectives—To examine the effects of aging and neuropsychological (NP) impairment on driving simulator performance within a human immunodeficiency virus (HIV)-infected cohort.

Methods—Participants included 79 HIV-infected adults (n = 58 > age 50, n = 21 < 40) who completed a NP battery and a personnel computer-based driving simulator task. Outcome variables included total completion time (time) and number of city blocks to complete the task (blocks).

Results—Compared to the younger group, the older group was less efficient in their route finding (blocks over optimum: 25.9 [20.1] vs 14.4 [16.9]; $P = .02$) and took longer to complete the task (time: 1297.6 [577.6] vs 804.4 [458.5] seconds; $P = .001$). Regression models within the older adult group indicated that visuospatial abilities (blocks: $b = -0.40$, $P < .001$; time: $b = -0.40$, $P = .001$) and attention (blocks: $b = -0.49$, $P = .001$; time: $b = -0.42$, $P = .006$) independently predicted simulator performance. The NP-impaired group performed more poorly on both time and blocks, compared to the NP normal group.

Conclusions—Older HIV-infected adults may be at risk of driving-related functional compromise secondary to HIV-associated neurocognitive decline.

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Keywords

HIV; aging; driving performance; independent functioning; cognition

Introduction

A variety of investigations employing self-reported driving histories, driving simulators, and on-the-road driving evaluations have found that neurocognitive deficits may be related to reduced driving capacity.¹⁻⁵ As many as 29% of the human immunodeficiency virus (HIV)-infected individuals report reduced driving capability,⁶ and there appears to be a higher likelihood of both poorer driving simulator performance⁷ and real-world driving ability (as assessed via a structured on-road evaluation) among neuropsychologically impaired HIV-sero-positive patients.⁸ Importantly, both neuropsychological (NP) decrements and poor driving simulator performance have been shown to predict real-world driving difficulties in HIV,⁸ supporting the utility of laboratory-based measurements in detecting everyday functional capacity.

Compromised driving ability in patients with HIV infection remains a relatively unexplored area of research. In the earliest known research investigating the effects of NP impairment upon driving capacity in HIV-infected individuals, Marcotte and colleagues⁷ revealed that mildly cognitively impaired patients failed simulation-based driving evaluations 5 to 6 times more frequently than cognitively intact counterparts. Furthermore, these authors demonstrated that driving ability was predicted by NP performance in several areas, including attention, fine motor abilities, visuoconstruction, and nonverbal memory. In a follow-up study, Marcotte and colleagues⁸ examined HIV-related driving performance using 2 driving simulations (assessing navigational abilities and evasive driving) and an on-road evaluation, paired with a NP battery and a task of visual processing and attention (Useful Field of View test). Neuropsychologically impaired HIV-infected participants demonstrated a greater number of simulator crashes, reduced navigational skills, higher rates of failure in on-road driving tests, and decreased visual processing and divided attention when compared to cognitively-intact HIV infected patients and control participants. Moreover, nearly 48% of the variance in on-road driving performance was predicted by global cognitive functioning and simulator performance. In this study, executive functioning emerged as the key neurocognitive predictor of on-the-road driving failure rates. An additional study conducted by Marcotte and colleagues⁹ utilized a task of visual processing and attention (Useful Field of View test), NP status, and detailed self-reported driving history. Neuropsychologically impaired HIV-positive patients demonstrated greater driving impairment than both HIV sero-positive and HIV sero-negative nonimpaired groups on driving measures. Poor attention was associated with a greater number of self-reported crashes, and in this relatively small sample 93% of the HIV-positive participants who did, or did not, have a prior automobile accident were correctly classified when poor attention and general NP impairment were considered simultaneously. The aforementioned studies suggest that neurocognitive compromise among HIV-infected adults has been strongly linked to impaired driving capacity across a variety of driving research paradigms.

Older HIV-infected individuals may be particularly at risk of cognitive compromise¹⁰⁻¹² as they show poorer cognitive performance than their younger counterparts, including reduced executive functioning, verbal and visual memory, and motor speed.¹³ Clinical outcome appears to be worse in older HIV-positive adults relative to younger patients, where older HIV-positive patients demonstrate a shortened time between HIV infection and AIDS diagnosis, a higher mortality rate following an AIDS diagnosis, and a briefer latency between AIDS diagnosis and onset of dementia.¹⁴⁻¹⁸ The HIV-related neurocognitive

deficits closely resemble normal aging processes as well as other subcortical dementias, a factor that complicates differential diagnosis.¹⁹ Results from our laboratory have demonstrated that aging exacerbates the neurocognitive effects of HIV infection, particularly among patients who have progressed to AIDS,²⁰ and that the combined effects of older age and neurocognitive decline are associated with poorer medication adherence.¹²

A number of studies have addressed driving performance among aging individuals and in this regard²¹ found that poor simulated driving performance explained over two-thirds of the variability in actual on-road driving in a group of elderly adults (ages 60+). Other studies have highlighted the relationships between cognitive dysfunction and poor driving performance among older adult samples. In particular, one study¹ showed that despite adequate accident avoidance, older drivers were slower to respond and fixate upon hazardous stimuli than were younger drivers. Similar findings have been reported in other studies, including those in which specific cognitive abilities were assessed via driving simulation tasks, including working memory,²² visual attention,²³ and divided attention.²⁴

Given the potential increased safety concerns posed by aging and the HIV disease process, driving capacity constitutes an especially important issue for older HIV-positive adults. The purpose of the present study was to examine the functional impact of NP impairment on an important component of everyday functioning (driving) among an older HIV-infected cohort. We specifically sought to examine (1) the effect of aging on driving performance among HIV-positive individuals and (2) NP predictors of driving simulator performance in this population.

Method

Participants

Participants included 79 HIV-positive adults recruited from local hospitals and community agencies in the Los Angeles area. Participants were aged between 21 and 79 years and were stratified by age group (younger group 18-39 years of age [$n = 21$]; older group 50-79 years of age [$n = 58$]). Exclusion criteria included a history of central nervous system infection apart from HIV, seizure disorder, learning disability, or traumatic brain injury with a loss of consciousness greater than 30 minutes. There were few individuals with current substance use/abuse (2 in the older group, 4 in the younger group) and none with dependence, although the proportion was significantly higher in the younger group. Study analyses were re-run when excluding these participants, and no significant differences in the findings emerged. There were no differences between older and younger groups in the presence of psychiatric disorder. Finally, there were no significant differences between older and younger groups in the number of months since they had last driven ($P > .05$). For the total sample, 53.8% of the participants reported that they are currently actively driving and 60 (76.9%) participants had driven within the last year. A total of 27.8% of participants denied a history of ever having received a ticket for a traffic violation.

For the younger group, the mean number of miles driven per month over the course of a 12-month period was reported to be 326.3 miles (standard deviation [SD] = 584.6; median = 15; range: 0-2100 miles), whereas the mean number of miles driven per month previously (per history) was reported to be 417 miles (SD = 856.3; median 5; range: 0-3600 miles) 2 years ago and 475.5 miles (961.4; median = 15; range: 0-4200 miles) 3 years ago. The mean number of reported lifetime traffic violations (not including parking tickets) was 2.4 (SD = 3.4; median = 1; range = 0-10). The mean number of months since last driven was 51.2 months (SD = 124.4; median = 0; range: 0-432 months). Forty percentage of the younger participants reported that they are currently actively driving.

For the older group, the mean number of miles driven per month over the course of a 12-month period was reported to be 316.0 miles (SD = 584.0; median = 90; range: 0-2500), whereas the mean number of miles driven per month previously (per history) was reported to be 241.9 miles (SD = 374.7; median=100; range: 0-1500) 2 years ago, and 510.8 miles (SD = 1694.9; median = 150; range:0-1200) 3 years ago. The mean number of reported lifetime traffic violations (not including parking tickets) was 3.5 (SD = 3.7; median = 3; range = 0-20). The mean number of months since last driven was 18.0 months (SD = 40.1; median: 0; range: 0-180 months). Fifty-nine percentage of the older participants reported that they are currently actively driving. Descriptive statistics for demographic data are shown in Table 1.

Procedure

All participants completed a comprehensive NP evaluation administered by trained psychometrists and supervised by a board-certified neuropsychologist (C.H.H.). In addition, extensive medical history data were collected using self-reported questionnaires. Past and present psychiatric status was determined using the Structured Clinical Interview for Diagnostic and Statistical Manual of Mental Disorders (Fourth Edition [*DSM-IV*]; SCID²⁵). Driving ability was measured using a laboratory-based driving simulator task (STISIM driving version 2.0 software,²⁶ Systems Technology, Inc, Hawthorne, California).

Measures

Neuropsychological Function—Raw test scores were converted to demographically corrected *t* scores that operate with a mean of 50 and a SD of 10 using published normative data, adjusting for age, education, gender, and ethnicity where appropriate. Test scores were grouped by neurocognitive domain, and domain *t* scores were obtained by calculating the mean *t* score for all the tests comprising a given domain. A global *t* score was calculated by summing individual test *t* scores and dividing by the number of tests administered. We assessed 7 domains of neurocognitive functioning, including the following:

Executive functioning was assessed using the Trail Making Test Part B²⁷ (norms²⁸), the Wisconsin Card Sorting test²⁹, and the Stroop Color-Word Interference test (Stroop³⁰). Information processing speed was assessed using the Trail Making Test Part A²⁷ (norms²⁸), the Color Naming and Word Reading Conditions from the Stroop³⁰, and the Wechsler Adult Intelligence Scale—3rd Edition Digit Symbol and Symbol Search subtests.³¹ Language was assessed using the Boston Naming test³² (norms²⁷), and the Controlled Oral Word Association test³³ (FAS and Animal; norms²⁷). Attention and working memory was assessed using the Paced Auditory Serial Addition Test Series 1 only³⁴ and WAIS-III Letter Number Sequencing subtest.³¹ Motor functioning was assessed using the Grooved Pegboard³⁵ (norms²⁷) Dominant and Nondominant hands. Visuospatial ability was assessed using the WAIS-III Block Design.³¹ Learning and memory were assessed using the Hopkins Verbal Learning Test—Revised³⁶ Total Learning and Delayed Recall scores, and the Brief Visuospatial Memory Test—Revised³⁷ Total Learning and Delayed Recall scores. Global cognitive functioning was defined as the mean score across the above 7 domains.

For post hoc analyses, Global Deficit Scores (GDS) were calculated using an algorithm developed by Heaton and colleagues.^{28,38} Individuals were assigned to NP-impaired versus unimpaired groups based upon these calculations. The GDS is a rating that quantifies both the number and the severity of impaired NP performances, and is computed by converting demographically corrected *t* scores on individual NP tests to deficit scores that range from 0 (indicating no cognitive impairment) to 5 (indicating normal cognitive function). In particular, the algorithm assigns an impairment rating to *t* scores as follows: $T > 39 = 0$; $39 \geq T \geq 35 = 1$; $34 \geq T \geq 30 = 2$; $29 \geq T \geq 25 = 3$; $24 \geq T \geq 20 = 4$; $T < 20 = 5$. The mean of all

individual test deficit scores constitutes the total GDS. Previous work³⁹ has demonstrated the utility of the GDS approach for classifying NP impairment among HIV-sero-positive individuals and for discriminating between HIV-positive patients and controls. For the present study, individuals with a GDS of 1.0 or greater were assigned to the NP-impaired group, whereas individuals falling below this threshold were assigned to the NP unimpaired group. In order to ensure that participants in the NP-impaired group demonstrated significant NP impairment, we opted to implement this more conservative cutpoint of 1. For the older group, 34.9% of the participants had a GDS of 1.0. For the younger group, 16.7% of participants had a GDS of 1.0.

Driving Ability—Driving ability was assessed using the laboratory-based STISIM driving simulator task (Systems Technology, Inc²⁶). For this simulation, participants were asked to drive to a designated location within a virtual city, and then to return to their starting point with the assistance of a map. The virtual city comprised a grid totaling 5-by-6 blocks of residential and commercial streets that were divided by a park. The roadway included major and local roads as well as 1-way streets. Participants were required to obey traffic signs (eg, stop signs and 1-way street signs). Potential obstructions (eg, pedestrians or other vehicles) were not present. Participants were provided with a map of the city and instructed to use the most efficient route to drive from a marked starting location to a designated gas station indicated on the map and then return to their starting location, also indicated on the map. They were permitted to consult the map as often as needed and to draw on the map or write directions for themselves.

Outcome variables included total time to task completion (time) and the total number of city blocks driven (blocks). The number of blocks represented the efficiency with which participants were able to complete the task (eg, avoiding incorrect turns or becoming lost). A minimum of 22 blocks was required for task completion, and thus this score comprised the optimal score for the “blocks” efficiency score. Thus, 22 was subtracted from each participant's total blocks score in order to obtain a value for the number of blocks required above optimal performance. Consistent with a previous study utilizing this driving simulator task,⁸ outliers on “time” and “blocks” (defined as 2 standard deviations from the mean, including participants who did fail to complete the task) were Winsorized and modified so that they were 1 unit higher than the next lowest score. For the present study, this value was 1958 seconds for “total time” and 72 blocks for “total blocks.” Each block driven the wrong way was added to the number of total blocks over the optimal number of blocks in order to account for these driving errors. The validity of driving simulation as a representation of real-world driving ability has been demonstrated in a variety of populations.^{8,21,40,41}

Statistical analyses included 1 way-analysis of variances (ANOVAs, controlling for length of time since the participant last drove), multiple regression models, and Pearson's *r* bivariate correlational analyses. The ANOVAs were employed to examine differences between age groups on driving simulator performance for total blocks and time. Multiple regression analyses were used to examine the neurocognitive contributions to driving simulator performance within each of the age groups. Post hoc ANOVAs were conducted between impairment groups within the older subsample to determine whether driving decrements would be specific to neurocognitively impaired individuals. Finally, Pearson correlations were used to examine relationships between driving performance and global NP status within impaired older and younger groups.

Results

There were no significant differences between age groups in time since last driven (months: younger = 9.8 [19.1], older = 33.4 [82.1]; $P > .05$; $F_{1,74} = 1.526$, $P = .22$). Using NP test

scores that already adjust for age (mean adjusted T scores), the older and younger HIV-positive groups had significantly different ($F_{1,77} = 5.82$; $P = .02$) performance in the visuospatial domain only (older: $M = 46.84$ [9.56]; younger: $M = 53.06$ [11.57]), although trend findings were found between older ($M = 43.86$ [6.89]) and younger ($M = 47.11$ [6.68]) HIV-positive adults for the processing speed domain ($F_{1,77} = 3.50$; $P = .065$). For the total sample, there was a significant relationship between becoming “lost” while driving (ie, wrong way) in the virtual environment and both total time ($r = .38$; $P = .001$) and total blocks ($r = .25$, $P = .02$). Univariate analyses revealed that the older adults (26.3 [20.1]) performed significantly worse than younger adults (15.3 [17.7]) on total blocks (beyond optimum; $F_{1,77} = 5.5$, $P = .02$, $\eta^2 = 0.06$). Univariate analyses also indicated that the older adults (1297.6 [577.6]) performed more poorly than younger adults (804.4 [458.5]) on total time to task completion ($F_{1,77} = 12.4$, $P = .001$, $\eta^2 = .15$). Importantly, ANOVA findings comparing older and younger age groups on driving performance continued to remain significant even when controlling for miles driven (total blocks: $F_{1,5,111} = .027$, partial $\eta^2 = 0.070$; total time: $F_{1,11,228} = 0.001$ partial $\eta^2 = 0.142$). See Table 2 for descriptive statistics of NP and driving performances by age group. In order to explore the basis for this poorer performance on the driving simulator among older adults, NP test performance was regressed on driving simulator performance. Predictor variables included each of the 6 domains of cognitive function, including executive functioning, information processing speed, language, attention and working memory, visuospatial ability, and learning/memory. These variables were entered simultaneously into the regression model. Given the high degree of multicollinearity between a variety of NP predictor variables and global cognition ($r = .50-.83$), this general measure was not included in the model. Four standard multiple regression tests were conducted; analyses were run for both older and younger groups separately, and total time and total blocks served as the criterion variables.

For the older group only, the full models were significant for both total time to completion (older: $F_{7,50} = 67.71$; $P < .001$) and total number of blocks driven (older: $F_{7,50} = 9.37$; $P < .001$). Results for younger adults were nonsignificant for total time ($F_{7,13} = 1.02$; $P = 0.46$) and total blocks ($F_{7,13} = 1.37$; $P = .27$). Among the older adults, NP test scores accounted for 52% of the variance of total time to task completion. Both visuospatial abilities ($b = -0.40$; $t = -3.4$; $P = .001$) and attention ($b = -0.42$; $t = -2.9$; $P = .006$) independently predicted total time to task completion for the older adults. Additionally, for the older adults, NP test scores accounted for 57% of the variance of total blocks driven, and again both visuospatial abilities ($b = -0.40$; $t = -0.40$; $P < .001$) and attention ($b = -0.49$, $t = -3.5$; $P = .001$) independently contributed total blocks driven for the older adults. Neither of the regression model was significant for the younger group.

To determine whether there was potential impact of current driving status (driving versus not driving) on results, we subsequently ran hierarchical multiple regression analyses, controlling for driving status. Driving status was entered in the first step and all NP domains were entered in the second step. Results were consistent with primary study analyses, and suggested significant results for older (but not younger) adults on number of blocks driven ($F_{8,48} = 7.634$, $P = .001$; $R^2 = 0.56$) and total time completion ($F_{8,48} = 6.243$, $P < .001$; $R^2 = 0.51$). Again attention (blocks driven: $b = -0.47$, $t = -3.38$, $P = .001$; total time: $b = -0.40$, $t = -2.79$, $P = .008$) and visuospatial (blocks driven: $b = -0.40$, $t = -3.43$, $P = .001$; total time: $b = -0.40$, $t = -2.79$, $P = .008$) functions contributed significantly and independently to both the models. The models again failed to reach significance for the younger adult group.

Table 3 depicts relationships between the NP domains and driving performances per age group. Note that although many cognition-driving relationships hold for the younger group in univariate analyses (total time is associated with global NP function, attention, information processing speed, and executive functioning; total block [optimized] is

associated with global NP function, executive functioning, information processing speed, attention, and learning/memory), these results no longer remain when all other NP domain variables are held constant in the standard multiple regression models.

In order to further explore the factors contributing to our regression findings for the older group, we elected to classify these patients as neuropsychologically impaired versus unimpaired using the GDS, as described above. Post hoc ANOVAs were then conducted to determine whether the older adult group differed in driving performance as a function of NP impairment status. These results were not carried out for the younger group given the inadequate number of younger participants ($n = 3$) with impaired NP data. Results indicated significant impairment group differences among the older adults for both total blocks ($F_{1,56} = 8.30$; $P = .006$) and total time ($F_{1,56} = 8.00$; $P = .006$), with impaired older participants (total blocks $M = 38.5$ [19.4]; total time $M = 1640.3$ [469.4]) performing significantly more poorly than unimpaired older participants (total blocks $M = 22.1$ [18.8]; total time $M = 1178.0$ [568.0] on driving performance variables). Given that higher total time may indicate driving failures unrelated to slowness (eg, becoming lost), we also compared groups on time divided by total blocks in order to determine whether older individuals were also slower in undertaking the task. Results were significant and revealed that older adults perform significantly more slowly on this task when correcting for total blocks (older: $M = 27.1$ [6.7]; younger: $M = 21.6$ [4.6]; $P = .001$).

Finally, correlational analyses were conducted to examine the pattern of relationships between global NP function and driving ability among impaired individuals by age group. Results indicated significant relationships between global NP ability and both total time ($r = .55$; $P = .04$) and total blocks ($r = -0.58$; $P = .03$) for the older adult group. These analyses were not conducted for the younger group due to inadequate sample size (younger unimpaired $n = 18$; younger impaired $n = 3$).

Conclusions

Results of this study indicated that the driving performances of older HIV-infected adults (age 50) on a route-planning virtual city task were significantly less efficient and slower than those of younger HIV-infected adults (age <40). Among older patients, NP test scores accounted for 54% of the variance on task completion and 57% of the variance on efficiency of the route. Attention and visuospatial abilities were the domains maximally predictive of impaired driving performance on these driving efficiency and speed variables for the older group. This effect seems to be somewhat specific to older adults with NP impairment, as significant relationships between driving ability and NP status were not found for younger adults or older adults without documented cognitive impairment. Of note is that results remained significant even when controlling for current driving status.

To our knowledge, this is the first study to examine the driving performance among HIV-sero-positive older adults. Our results support previous research that has documented greater driving decrements among healthy older adults when compared to younger counterparts^{1,42,43}; these previous studies have generally attributed declines in driving performance to visual attentional dysfunction,^{44,24,23,45} which we found to be 1 of the 2 main cognitive impairments responsible for the driving inefficiency and slowness observed among older HIV-positive adults. It should be noted that we did not employ a classical measure of visual attention, such as the Useful Field of View test, although these results do reflect a relationship between complex auditory attention and driving performance. These results appear to be consistent with the investigation of healthy aging that has found relationships between impaired driving and attention/vigilance. Campagne et al⁴² examined driving abilities as they related to vigilance in age groups stratified by 10-year increments,

and results showed that lower frequency waking electroencephalogram (theta) activity was associated with deviations in speed and running-off-the-road incidents in the oldest group when compared to young- and middle-aged drivers, suggesting that when compared to younger drivers, older adults' driving performance may be more affected by reduced vigilance. Although our study did not address vigilance per se, the association between driving variables and visual attention in HIV suggests a possible common thread (ie, visual attention defined broadly) among aging individuals.

Studies examining driving performance among older cognitively impaired populations have revealed greater risk of driving impairment when compared to individuals without dementia or cognitive compromise,⁴⁶⁻⁴⁹ and consistent with our findings, visuospatial and visual attentional declines appear to be among the most notable cognitive factors predictive of impaired driving among these compromised populations.^{48,47} Longitudinal study of cognitively impaired older adults has demonstrated declining driving performance among patients with Alzheimer's disease, at a rate that was significantly more rapid than for nondemented aging individuals.⁴⁶ Factors including greater severity of dementia, increased age, and lower education predicted higher rates of failure on the driving assessment. Thus, older adults with notable NP compromise demonstrate even greater driving failures than healthy aging individuals, and are consistent with the present study, which indicated the greatest driving performance decrements among older neuropsychologically impaired HIV-positive patients.

Moreover, accelerated (24% increased) driving errors have been documented among aging individuals even without the presence of neurologic diagnosis, and deficits in general cognition, motor skill, and vision may serve to support these changes. Visuomotor and visuospatial changes in particular may be associated with especially poor driving among elderly individuals. This age-related decline appears to be specific to older drivers since this effect was not apparent among middle-aged drivers.⁵⁰ Cushman⁵¹ also found the oldest individuals to be at greatest risk of failing-on-the-road driving standards, and showed selective visual attention to be the most important predictor of driving performance in the elderly individuals, a finding that we have also documented with the present sample. Among older individuals with putative frontostriatal involvement, older age together with poorer performances on tests of visual, visuo-attentional, and general cognitive functioning predicted driving-related errors.⁵²

Recent investigation strongly suggests an interaction between cognition and broad instrumental functional decline in HIV, with relationships to medication adherence,⁵³ financial management, cooking, and employment.⁵⁴ Furthermore, older HIV-positive adults (who are at substantially increased risk of cognitive decline^{11,55}) in particular are at risk of functional decline including poorer medication adherence.⁵⁶ Indeed, the relationship between cognitive impairment and functional compromise in HIV may be moderated by age, with older adults demonstrating poorer outcomes overall, and our results show that this cognition–function relationship also appears to extend to driving performance.

We also found that driving speed and efficiency variables differ by NP impairment group, with NP-impaired individuals performing more poorly on both the measures. It should also be highlighted that relationships between driving ability and NP status were found only for impaired older adults, thus extending prior investigation of functional abilities in older HIV-infected individuals. Importantly, findings comparing older and younger age groups on driving performance continued to remain significant even when controlling for miles driven. Despite the absence of a sero-negative group, the possibility of an HIV/aging interactive effect is suggested by the current results, given that age entered a model that controlled for

normal cognitive aging, and when considering that normative corrections were applied to the NP data.

Recent investigations targeting other subcortical neurodegenerative diseases can serve to inform the neurophysiologic basis of our findings. Parkinson's disease is one such appropriate reference group given that the disease process also implicates the caudate of the basal ganglia.^{57,58} Studies of simulated driving in patients with Parkinson's disease have demonstrated greater decline across a variety of driving variables,⁵⁹⁻⁶² and research has highlighted that visual attention/perception and working memory (versus motor) deficits may be central to these driving performance decrements in Parkinson's disease.^{52,63,64,65} It is well accepted that HIV-dementia mimics the deficits observed in Parkinson's disease given its associated declines in attention and working memory, psychomotor speed, and executive functioning.^{66,67} The observed motor dysfunction and abnormal dopaminergic systems in HIV dementia suggests deterioration of the basal ganglia, a key brain system also impacted by Parkinson's disease.

Arguably, the most consistent structural magnetic resonance imaging finding to date is HIV-related atrophy of the caudate and the association between caudate volume loss and NP decrements. Alyward et al⁶⁸ demonstrated that individuals with HIV-associated dementia had smaller basal ganglia volumes in proportion to total brain volume when compared to HIV-positive individuals without dementia and HIV-negative individuals, and others have found significant relationships between basal ganglia atrophy and NP performance.⁶⁹⁻⁷¹ The caudate and putamen appear to be particularly implicated,^{65,71} and this basal ganglia atrophy also appears to persist even in the presence of highly active antiretroviral therapy-regulated disease.⁷² The results of the present study suggest that functional decrements in driving ability may be mediated by corresponding dysfunctional frontal-striatal circuitry. Our findings also suggest even greater driving compromise for individuals presenting with marked risk of cognitive and functional reductions (ie, individuals of older age with HIV). These results further support the relationships of attention and visuospatial abilities with driving capacity in individuals at high risk of subcortical neurodegeneration. Since the principal findings in this study hold for our total older HIV-positive sample (including individuals with varying levels of NP impairment), our results appear to be relevant (although in attenuated form) even for HIV-infected individuals presenting with less significant levels of neurocognitive compromise. This suggests that functional compromise may be present even among individuals with milder levels of NP difficulty. It should be noted, however, that on-road driving assessments are necessary to determine with certainty whether individuals with poor simulated driving performance are also unsafe to drive. Although a previous study demonstrated that poor performance on the Virtual City was predictive of on-road driving in younger HIV-infected individuals,⁸ replication and further study are necessary to explore whether these simulated results map on to real-world driving capacity in these older cohorts.

Limitations

There are several limitations to this study. First, we did not have a sero-negative control group, and thus this investigation remains unequipped to selectively address effects that are specific to HIV or the interactive effects of advancing age and HIV status, and rather centers upon the broader study of the impact of HIV within an aging population. On the other hand, we did use normed NP test scores, so the fact that aging still entered a model that controlled for normal cognitive aging suggests the possibility of an HIV/aging interaction. Unfortunately, we could not address this directly with the current data. Therefore, future research should include a sero-negative control group in order to better address possible synergistic effects of advancing age and HIV illness upon driving capacity. Furthermore, the use of the driving simulator task allows for practical application of driving skills within the

laboratory setting, but cannot fully replicate real-world driving, and is thus limited in its ability to determine real-world driving safety. Finally, the unequal samples of our older and younger HIV-positive groups prohibited an analysis of the relationships between impaired and unimpaired younger HIV-positive individuals, and thus we are unable to comment upon this possible additional effect. Therefore, further study is needed to support the results reported here.

Summary and Clinical Implications

The results of this study suggest that older HIV-infected adults may be at increased risk of functional compromise secondary to HIV-associated neurocognitive decline, with attention and visuospatial abilities constituting the neurocognitive domains maximally predictive of driving-related navigational performance. Driving is a highly demanding and potentially hazardous daily activity, and these findings suggest that older HIV-infected adults with reduced visuospatial and attentional abilities may be at particular risk of impaired driving ability. This work extends the well-substantiated findings of reduced cognitive capacity among older HIV-infected individuals (eg, divided attention, visual attention and visual processing, and executive function), and provides support for the relationships between these neurocognitive deficits and driving decrements.

Effective patient care requires that clinicians determine whether driving vulnerability is present, recommend further driving evaluation if relevant, consider the psychosocial impact of possible driving cessation among at-risk patients, and intervene where appropriate. Older age and the presence of cognitive impairment, and in particular declines in visuospatial and attentional function should be key considerations when evaluating for driving risk in HIV-positive patients. Early interventions designed to improve driving among vulnerable individuals may include rehabilitation of functional limitations (eg, physical), vehicle optimizations tailored to the needs of drivers, cognitive remediation (eg, processing speed⁷³), and educational interventions⁷⁴ intended to improve understanding and facilitate family discussion of issues related to driving cessation, whereas early options to help patients prepare for driving cessation might include discussion of public transport options, consideration of the feasibility of relocation, and facilitating transport arrangements with friends and family. In general, social interaction and mobility should be targeted and are likely to serve as positive psychosocial support for individuals undergoing driving cessation.⁷⁵

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Table 1

Demographic and Health Characteristics of Participant Group.

	Younger (<40 years)	Older (>50 years)	F	P
N = 79	21	58		
% Female	28.6%	19%	–	NS
Mean age in years ^a (SD)	33.95 (4.93)	54.98 (5.39)	245.131	<.001
Mean years education ^a (SD)	12.14 (2.27)	13.78 (2.27)	7.981	.006
Estimated premorbid IQ (SD)	97.33 (15.94)	98.69 (15.84)	–	NS
Last drove (years)	Median = 0 (0.0, 12.0)	Median = 0 (0.0, 22.0)	–	NS
Mean of most recent CD4 (SD)	479.63 (265.87)	479.03 (273.44)	–	NS
Nadir CD4 (SD)	138.85 (129.79)	215.91 (175)	–	NS
Mean of most recent viral load Lg10 (SD)	2.4 (1.45)	2.86 (1.09)	–	NS
Viral load undetectable (less than 50 copies/mL)	62%	69%	–	NS
Mean years since HIV diagnosis ^b (SD)	11.1 (5.49)	14.6 (.6.75)	4.569	.036
Length of antiretroviral treatment	2.70 (0.66)	2.76 (0.54)	–	NS
% Opportunistic infection	47.6%	37.9%	–	NS
% Meet criteria for AIDS diagnosis	66.7%	69.6%	–	NS
Current psychiatric disorder	23.5%	9.4%	–	NS
Current substance use	23.5%	3.6%	–	.021
Ethnicity/race				
% Hispanic or Latino/Latina	28.6%	10.3%	–	NS
% Asian	4.8%	1.7%	–	NS
% African American/black	28.6%	48.3%	–	NS
% Caucasian/white	28.6%	36.2%	–	NS
% Multiracial	9.5%	1.7%	–	NS

Abbreviations: ns, not significant; SD, standard deviation; CD4, cluster of differentiation 4.

^a $P < .01$.^b $P < .05$.

Table 2

Neuropsychological and Driving Performance by Age.

	Younger (<40 years)	Older (>50 years)	<i>F</i>	<i>P</i> ^a
N = 79	21	58		
Neuropsychological domains				
Visuospatial	53.06 (11.57)	46.84 (9.56)	5.82	.02 ^a
Processing speed	47.11 (6.68)	43.86 (6.89)	3.50	.07
Attention	43.19 (8.81)	46.42 (8.94)	2.03	.16
Executive function	48.13 (6.28)	46.56 (8.36)	0.61	.44
Motor	44.31 (8.27)	43.95 (9.14)	0.03	.87
Learning/memory	43.21 (11.01)	38.56 (12.55)	2.23	.14
Language	46.41 (8.86)	48.05 (8.51)	0.56	.46
Driving domains				
Total time (seconds)	804.38 (458.52)	1297.59 (577.56)	–	.028 ^a
Total blocks (above optimal performance)	14.38 16.89	25.93 (20.13)	–	.001 ^b

^a*P* .05.^b*P* .001.

Table 3

Pearson's Bivariate Correlations for Neuropsychological Domain Scores and Driving Simulator Performance Per Group.

	Global	Visuospatial	Motor	Executive	Information Processing	Language	Attention	Memory
Total time								
Younger								
Pearson correlation	-.458	-.232	-.084	-.519	-.466	-.302	-.573	-.252
Significance (2-tailed)	.037 ^a	.313	.718	.016 ^a	.033 ^a	.183	.007 ^b	.270
Older								
Pearson correlation	-.571	-.583	-.439	-.366	-.416	-.392	-.548	-.448
Significance (2-tailed)	<.001 ^c	<.001 ^c	.001 ^c	.005 ^b	.001 ^c	.002 ^b	<.001 ^c	<.001 ^c
Total blocks								
Younger								
Pearson correlation	-.499	-.202	.050	-.501	-.411	-.321	-.584	-.395
Significance (2-tailed)	.021 ^a	.190	.145	.010 ^b	.032 ^a	.078	.003 ^b	.038 ^a
Older								
Pearson correlation	-.590	-.577	-.375	-.442	-.379	-.474	-.618	-.447
Significance (2-tailed)	<.001 ^c	<.001 ^c	.002 ^b	<.001 ^c	.002 ^b	<.001 ^c	<.001 ^c	<.001 ^c

^a P .05.

^b P .01.

^c P .001.