Association of Functional Impairments and Co-Morbid Conditions with Driving Performance among Cognitively Normal Older Adults

David B. Carr¹ *, Peggy P. Barco², Ganesh M. Babulal³, Sarah H. Stout³,⁴, Anne M. Johnson⁵, Chengjie Xiong⁶, John C. Morris³,⁴,⁷, Catherine M. Roe³

¹ Division of Geriatrics and Nutritional Science, Division of Neurorehabilitation, Washington University in St. Louis, The Rehabilitation Institute of St. Louis (TRISL), Parc Provence, St. Louis, MO, United States of America, ² Program in Occupational Therapy, Washington University in St. Louis, St. Louis, MO, United States of America, ³ Department of Neurology, Washington University in St. Louis, St. Louis, MO, United States of America, ⁴ Knight Alzheimer’s Disease Research Center, Washington University in St. Louis, St. Louis, MO, United States of America, ⁵ Center for Clinical Studies, Washington University in St. Louis, St. Louis, MO, United States of America, ⁶ Division of Biostatistics, Washington University in St. Louis, St. Louis, MO, United States of America, ⁷ The Center for Aging, Memory and Aging Project, Washington University in St. Louis, St. Louis, MO, United States of America

* DCarr@wustl.edu

Abstract

Objectives
To examine the relationship between key functional impairments, co-morbid conditions and driving performance in a sample of cognitively normal older adults.

Design
Prospective observational study

Setting
The Knight Alzheimer’s Disease Research Center, Washington University at St. Louis

Participants
Individuals with normal cognition, 64.9 to 88.2 years old (N = 129), with a valid driver’s license, who were currently driving at least once per week, and who had participated in longitudinal studies at the Knight Alzheimer’s Disease Research Center

Measurements
Static visual acuity, contrast sensitivity, physical frailty measures, motor skills, total medical conditions, and the modified Washington University Road Test.

Results
When controlling for age, race, gender, APOE, and education the total number of medical conditions was unassociated with both road test scores (pass vs. marginal + fail) and the total driver error count. There were marginal associations of our measure of physical frailty (p = 0.06) and contrast sensitivity score (p = 0.06) with total driving error count.
Conclusion

Future research that focuses on older adults and driving should consider adopting measures of physical frailty and contrast sensitivity, especially in samples that may have a propensity for disease impacting visual and/or physical function (e.g. osteoarthritis, Parkinson’s, eye disorders, advanced age >80 years, etc.).

Introduction

Driving an automobile is a crucial instrumental activity of daily living and it can become increasingly difficult with age. Approximately 200,000 of the 30 million drivers 65 years of age or older in the United States are injured in motor vehicle crashes each year [1] and there were over 4,000 motor vehicle deaths for those aged 70 years or older in 2014 [2]. Even though many older persons self-restrict their driving to compensate for age-related changes and diseases [3], crash rates per mile traveled start increasing for drivers at age 70 and older and are highest after age 85 [1]. Furthermore, two longitudinal driving studies that included samples of cognitively intact older adults have revealed deterioration in driving performance over time on standardized performance based road tests [4, 5].

The etiology for this decline in driving performance is unclear. Our study group recently published on a sample of 129 cognitively normal older adults and found an increased number of driving errors associated with increasing levels of molecular biomarkers for Alzheimer disease (AD), suggesting a possible functional correlate of preclinical AD [6]. However, other causes should also be considered since functional impairments in other key domains required for driving (e.g. vision, motor ability) and/or additional co-morbid conditions (e.g. diabetes, heart disease) could impair driving performance via other mechanisms.

Impairments in vision and neuromuscular strength and speed have been linked to crash risk for older adults [7]. Common age-related eye diseases such as macular degeneration, cataracts and glaucoma, may result in subsequent loss of contrast sensitivity and restricted visual fields, which have been associated with impaired driving [8, 9]. Reduced neck rotation, orthostatic drop in blood pressure, slow foot reaction time and a history of a fall have been associated with increase crash risk [10–12]. Use of certain medications, including benzodiazepines, opioid analgesics, alcohol, muscle relaxants, sedating antihistamines and antidepressants, is also linked to increased risk [13, 14]. A myriad of medical conditions associated with impaired driving performance and increased crash risk have also been the subject of recent reviews [15, 16].

In this study, we examined the relationship between key functional impairments, co-morbid conditions and driving performance in a sample of cognitively normal older adults. We tested whether the presence of functional impairment and comorbid conditions were associated with road test errors. We hypothesized that multiple medications and medical conditions or the presence of visual and/or physical functional impairment would be associated with worsening driving performance.

Materials and Methods

Design

Participants with normal cognition (Clinical Dementia Rating [CDR] = 0) [17], aged 65 years and older, with a valid driver’s license, and who were currently driving at least once per week,
were recruited for this cross-sectional study (AG043434) from participants in longitudinal studies at the Knight Alzheimer’s Disease Research Center (ADRC). At baseline, participants took part in annual clinical and psychometric assessments performed by the clinical core in the Knight ADRC. This was followed by additional functional based measures associated with impaired driving performance and then a standardized performance based road test. Written informed consent was obtained from all participants. This study was approved by the Washington University Human Studies Committee.

**Clinical and psychometric assessments**

A CDR is derived by experienced clinicians who synthesize information obtained from semi-structured interviews with the participant and separately with a collateral source that has familiarity with the participant. The CDR is derived in accordance with a standard scoring algorithm and only those CDR = 0 (cognitively normal) were recruited for this study.

**Measurement of functional domains**

**Vision.** The participant was assessed for far visual acuity by Early Treatment of Diabetic Retinopathy Study (ETDRS) Chart [18]. Contrast sensitivity was tested using the Pelli-Robson contrast sensitivity chart [19].

**Physical frailty.** Four measures of the 9-item Physical Performance Test PPT [20] were completed annually on participants and include timed ability to pick up a coin, timed 50-foot walk, time to perform 5 chair stands and balance testing. These four measures were combined for an overall frailty score. Only the time for the full tandem stance was selected for the balance measure, since this was the only balance subscore where any impairment was documented.

**Motor skills.** The clinician scored motor examination measures using the Unified Parkinson’s Disease Rating Scale: Part III [21], which uses a Likert scale (0–4, with higher scores indicating more impairment) to assess speech, facial expression, tremor at rest and with action, rigidity, finger taps, hand movements, leg agility, chair stands, posture, postural stability and gait.

**Measurement of co-morbid conditions**

**Medical conditions.** A total count of medical conditions was calculated at the baseline clinical assessment prior to the driving test by summing the number of medical conditions reported by the participant during the annual clinical assessment. The presence/history of the following active medical conditions in the past five years was assessed: myocardial infarction, cardiac arrest, atrial fibrillation, coronary artery disease, s/p coronary artery bypass graft, s/p pacemaker placement, congestive heart failure, stroke, transient ischemic attack (TIA), Parkinson’s disease, seizures, traumatic brain injury (TBI), hypertension, hypercholesterolemia, diabetes, B12 deficiency, thyroid disease, incontinence, depression, substance abuse, and psychiatric disorders not otherwise specified (NOS).

**Medications.** A total count of routine medications taken by each participant at the time of the baseline yearly clinical assessment prior to the driving assessment was obtained from the participant. Medications examined were antihypertensives (e.g. angiotensin converting enzyme Inhibitors, calcium channel blockers, angiotensin receptor blockers, benzodiazepines, statins, bladder agents, diabetic agents, tricyclic antidepressants, antiepileptic agents, hypnotics, antipsychotics, selective serotonin reuptake inhibitors, H2 receptor antagonists, Parkinson’s agents).

**Performance based road test.** The 12-mile, modified Washington University Road Test (mWURT), takes about an hour to complete and is scored using both ordinal methodology
and a quantitative count of total driving errors or abnormal behaviors (e.g. the Record of Driving Errors) [24]. The course begins in a closed parking lot so that the participant becomes familiar with the study car, a 4-door sedan, and then proceeds to a community in-traffic route which includes unprotected left hand turns, in addition to complex intersections and lane merges. Following directions delivered by an occupational therapy/driving rehabilitation specialist (OTR/DRS) sitting in the front seat, the participant drives throughout the mWURT route. A portion of the road course is self-directed driving. This aspect of the evaluation requires a participant to locate a specific store, find the entrance, park, and navigate out of the parking lot. The front-seat OTR/DRS can take control of the wheel if needed or apply a passenger-side brake. For the purposes of this analysis, road test performance was treated as a dichotomous outcome (i.e., pass ratings compared to marginal and fail ratings combined) [25]. The average time between the baseline annual assessment and the performance-based road test was 4.2 months.

**Statistical analyses.** Analyses were performed using SAS, version 6.0 (SAS Institute, Inc., Cary, NC). Logistic regression (for road test rating) and linear models (total number of road test errors), after adjusting for age, education, gender, race, and apolipoprotein E4 (APOE4), were used to test whether road test outcomes differed for the presence or absence of each functional domain measure or as a function of our co-morbidity index values (i.e. total number of medical conditions or medications).

**Results**

Individuals aged 64.9 years to 88.2 years (N = 129) met inclusion criteria (Table 1) and had the majority of clinical information available for analysis. Participants were of advanced age (avg. 73 years, predominantly Caucasian (~90%), of equal gender, highly educated, and with an expected normal mental status screen (average MMSE = 29). Twenty-nine % of the sample had at least one positive ApoE4 allele. Table 2 provides averages of our non-cognitive co-morbid and functional measures, which include total number of medical conditions, medication, physical frailty score, UPDRS score, visual acuity, and contrast sensitivity. However, only a subset of the sample had physical performance data recorded (N = 84), since participants in the Adult Children study did not have these annual measures (Table 2). When controlling for age, race, gender, APOE, and education the total number of medical conditions and medications were unassociated with both our qualitative road test scores (pass vs. marginal + fail) using logistic regression and the total driver error count, using linear regression. There were marginal associations of our measure of physical frailty (p = 0.06) and contrast sensitivity score (p = 0.06) with total driving error count (Tables 3 and 4).

| Characteristics          | Mean/(SD) |
|--------------------------|-----------|
| Age (years)              | 72.9 (4.9) |
| Minority (African-American) | 9.3%     |
| Gender (% Women)         | 53.5%     |
| Education, mean years, (SD) | 16.1(2.59) |
| MMSE, mean (SD)*         | 29.4(0.9) |
| Clinical Dementia Rating = 0, (%) | 100      |
| APOE4 presence of one allele | 29%      |

Abbreviations: APOE4 = apolipoprotein E; MMSE, Mini-Mental State Exam
* MMSE scores range from 0 (worst performance) to 30 (best performance)

doi:10.1371/journal.pone.0167751.t001
Discussion

We did not find evidence for an association between our comorbidity measures and road test performance (total number of driving errors or qualitative ratings). This may not be surprising given the voluntary nature of our cohort, which recruits healthy older adults in the community for longitudinal studies on memory and aging. The nature of our cohort, as reflected in Table 2, suggests a very low prevalence of co-morbid conditions and scores in the normal range on our functional measures.

We did find a marginal relationship between both physical frailty and contrast sensitivity with total driving error count. There could be several explanations for these findings. Motor decline has been noted in some studies on aging and driving and our driving sample may have captured a cohort of drivers with subtle, but significant, age-related sarcopenia and/or muscle weakness impacting driving performance [25, 26]. Another explanation for this potential relationship is preclinical AD itself. The physical frailty measures of time and reduced speed of processing might have been impacted by drivers with abnormal AD biomarkers. Contrast sensitivity has been associated with impaired driving performance in older adults. However, the Pelli-Robson Chart may not be as sensitive as other measures of contrast sensitivity [27]. Thus, we may have missed an opportunity for a more accurate measurement of this construct. In addition, the road course was done during the day and did not consistently present opportunities to challenge participants in low contrast settings. Finally, these marginal relationships may be spurious findings.

There were several limitations to this study. Static (non-dynamic/without movement) visual acuity is usually measured in performance based road test studies due to state licensing requirements. However, there is typically no correlation with this measure and driving performance [28]. Thus, the lack of relationship with this measure and driving ability in our sample is not surprising. The performance based road test was not recorded and reviewed by video and was based only on a one hour assessment. It is possible that a video recorded study over a longer period of time and/or a naturalistic study might have captured more errors that would

| Co-morbid/Functional Conditions | Mean (SD) |
|---------------------------------|-----------|
| Total Number of Medical Conditions | 1.5 (1.2) |
| Total Number of Medications | .8 (1) |
| Physical Frailty Sum Score (secs)/N = 84 | 12.4 (1.8) |
| UPDRS Total Score | 6.1 (12.5) |
| Far Visual Acuity OU (mean) | 26.1 (7.6) |
| Contrast Sensitivity (logMar) | 1.6 (.1) |

doi:10.1371/journal.pone.0167751.t002

Table 2. Summary of Functional Assessment/Co-morbidities (N = 129).

| Variable | Coefficient Estimate | Standard Error | t Value | Pr>|t| |
|----------|----------------------|----------------|---------|-----------|
| Intercept | -29.59298323 | 14.40705995 | -2.05 | 0.0434 |
| Physical Frailty Measure | -0.62810913 | 0.32952665 | -1.91 | 0.0604 |
| Education | 0.11268732 | 0.22447777 | 0.50 | 0.6171 |
| Gender | 1.28776597 | 1.08542959 | 1.19 | 0.2391 |
| Age | 0.38069143 | 0.11607072 | 3.28 | 0.0016 |
| Apoe4 | -1.41015024 | 1.16837862 | -1.21 | 0.2312 |
| Race | 3.11646881 | 2.18982702 | 1.42 | 0.1587 |

doi:10.1371/journal.pone.0167751.t003

Table 3. Regression Analysis of Physical Frailty Measure with Road Test Total Error Count.
pertain to driving safety. There is a small portion of our course that does require self-directed driving (i.e. strategic level). A course that requires more route planning and self-directed driving might reveal more driving performance concerns.

This research volunteer sample was recruited from the community and was relatively healthy. All 129 participants in this sample had molecular biomarkers studies for AD and this requirement limits the representativeness of the ADRC sample. Although participants are followed longitudinally, this manuscript reports on cross-sectional baseline data collected and those processed to date. These research volunteers may not be representative of the general population. A sample based in a medical setting would likely have more sizable co-morbidities and possibly shown a relationship with driving performance. Our measures of co-morbidity were a simple sum of the number of medications or medical conditions. A more detailed measure of disease severity that includes functional limitations such as the Geriatric Co-morbidity Index, may have revealed a relationship with driving ability [29]. Finally, we did not explore the contribution of cognitive impairment as measured by psychometric test performance in this paper. Stage III Preclinical AD [30] is manifested by impaired cognitive testing and will be the basis of a future study.

Conclusions

In summary, we did not find evidence in this sample for significant visual, motor or co-morbid conditions impacting driving performance. This may be in part related to the recruitment of healthy volunteers. The marginal relationship we found with physical frailty, contrast sensitivity and driving performance is interesting and may indicate that impairments in muscle strength, coordination, gait and/or balance and vision could still play a role either independently or perhaps along with “cognitive frailty” in preclinical AD, and contribute to driving decrements. Future research that focuses on older adults and driving research should consider adopting measures of physical frailty and contrast sensitivity, especially in samples that may have a propensity for disease impacting physical function (e.g. osteoarthritis, Parkinson’s, eye disorders, advanced age >80 years, etc.).

Supporting Information

S1 Driving Data. Functional Impairment and Comorbid Conditions dataset.
(XLSX)

Acknowledgments

The authors wish to thank Betsy Grant, Rosalia Alcoser and Josh Weng in the Division of Biostatistics at Washington University School of Medicine in St. Louis for their assistance with
data management and analysis; and Stephanie Paule-Martino from the Division of Geriatrics and Nutritional Science for her review and formatting of the manuscript. The authors thank the participants, investigators, and staff of the Knight ADRC Clinical Core for participant assessments, Genetics Core for APOE genotyping, Biomarker Core for cerebrospinal fluid analysis, and the Imaging Core for amyloid imaging. David B. Carr had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Author Contributions

Conceptualization: DBC PPB GMB SHS CMR.

Data curation: CX.

Formal analysis: DBC PPB CX JCM CMR.

Funding acquisition: JCM CMR.

Investigation: PPB SHS AMJ.

Methodology: DBC PPB GMB SHS JCM CMR.

Project administration: AMJ CMR.

Resources: AMJ CX.

Supervision: CMR.

Visualization: DBC PPB GMB.

Writing – original draft: DBC PPB GM.

Writing – review & editing: DBC PPB GMB SHS AMJ CX JCM CMR.

References

1. Centers for Disease Control and Prevention. Older Adult Drivers. 2015. http://www.cdc.gov/motorvehiclesafety/older_adult_drivers/index.html. (Accessed 2016 April 4).
2. Insurance Institute for Highway Safety. Older People. 2014. http://www.iihs.org/iihs/topics/t/older-drivers/fatalityfacts/older-people. (Accessed 2016 April 4).
3. Ragland DR, Satariano WA, MacLeod KE. Reasons Given by Older People for Limitation or Avoidance of Driving. The Gerontologist. 2004; 44(2): 237–44. PMID: 15075420
4. Duchek JM, Carr DB, Hunt L, Roe CM, Xiong C, Shah K, et al. Longitudinal driving performance in early-stage dementia of the Alzheimer type. Journal of the American Geriatrics Society. 2003; 51(10): 1342–7. PMID: 14511152
5. Ott BR, Heindel WC, Papandonatos GD, Festa EK, Davis JD, Dailello LA, et al. A longitudinal study of drivers with Alzheimer disease. Neurology. 2008; 70(14): 1171–8. doi: 10.1212/01.wnl.0000294469.27156.30 PMID: 18216302
6. Roe CM, Barco PP, Head DM, Ghoshal N, Selsor N, Babulal GM, et al. Amyloid Imaging, Cerebrospinal Fluid Biomarkers Predict Driving Performance Among Cognitively Normal Individuals. Alzheimer disease and associated disorders. 2016.
7. Ball KK, Roenker DL, Wadley VG, Edwards JD, Roth DL, McGwin G Jr., et al. Can high-risk older drivers be identified through performance-based measures in a Department of Motor Vehicles setting? J Am Geriatr Soc. 2006; 54(1): 77–84. doi: 10.1111/j.1532-5415.2005.00568.x PMID: 16420201
8. Szlyk JP, Mahler CL, Seiple W, Edward DP, Wilensky JT. Driving performance of glaucoma patients correlates with peripheral visual field loss. J Glaucoma. 2005; 14(2): 145–50. PMID: 15741817
9. Staplin L, Gish KW, Wagner EK. MaryPODS revisited: updated crash analysis and implications for screening program implementation. J Safety Res. 2003; 34(4): 389–97. PMID: 14636661
10. Marottoli RA, Richardson ED, Stowe MH, Miller EG, Brass LM, Cooney LM Jr., et al. Development of a test battery to identify older drivers at risk for self-reported adverse driving events. J Am Geriatr Soc. 1998; 46(5): 562–8. PMID: 9588368

11. Margolis KL, Kerani RP, McGovern P, Songer T, Cauley JA, Ensrud KE. Risk factors for motor vehicle crashes in older women. J Gerontol A Biol Sci Med Sci. 2002; 57(3): M186–91. PMID: 11867657

12. Isler RB, Parsonson BS, Hansson GJ. Age related effects of restricted head movements on the useful field of view of drivers. Accid Anal Prev. 1997; 29(6): 793–801. PMID: 9370015

13. Hetland A, Carr DB. Medications and Impaired Driving. Annals of Pharmacotherapy. 2014; 48(4): 494–506. doi: 10.1177/1060028014520882 PMID: 24473486

14. Bronnauer A, Lauz G, Geiger E, Soyka M, Moller HJ. Antidepressants and driving ability: results from a clinical study. J Clin Psychiatry. 2006; 67(11): 1776–81. PMID: 17196059

15. Dobbs BM. Medical Conditions and Driving: Current Knowledge, Final Report. Association for the Advancement of Automotive Medicine. NHTSA Publication: 2005 Contract No.: DTNH22-94-G-05297.

16. Charlton J, S Koppel, M Odell, et al. Influence of chronic illness on crash involvement of motor vehicle drivers: 2nd Edition. Monash University Accident Research Centre, Report #300. 2010. http://www.monash.edu.au/miri/research/reports/maurc300.pdf. (Accessed May 5, 2014).

17. Morris JC. The Clinical Dementia Rating (CDR): Current version and scoring rules. Neurology. 1993; 43(11): 2412–4.

18. Bailey IL JE Lovie. New Design Principles for Visual Acuity Letter Charts*. Optometry & Vision Science. 1976; 53(11): 740–5.

19. Pelli D, Robson J, editors. The design of a new letter chart for measuring contrast sensitivity. Clinical Vision Sciences; 1988: Citeseer.

20. Wilkins CH, Roe CM, Morris JC, Galvin JE. Mild physical impairment predicts future diagnosis of dementia of the Alzheimer’s type. Journal of the American Geriatrics Society. 2013; 61(7): 1055–9. doi: 10.1111/jgs.12255 PMID: 23647233

21. Goetz CG, Tilley BC, Shafstam SR, Stebbins GT, Fahn S, Martinez-Martin P, et al. Movement Disorder Society-sponsored revision of the Unified Parkinson’s Disease Rating Scale (MDS-UPDRS): Scale presentation and clinimetric testing results. Movement disorders. 2008; 23(15): 2129–70. doi: 10.1002/mds.22340 PMID: 19025984

22. Hunt LA, Murphy CF, Carr D, Duchek JM, Buckles V, Morris JC. Reliability of the Washington University Road Test: A performance-based assessment for drivers with dementia of the Alzheimer type. Archives of neurology. 1997; 54(6): 707–12. PMID: 9193205

23. Barco PP, Wallendorf MJ, Snellgrove CA, Ott BR, Carr DB. Predicting Road Test Performance in Drivers With Stroke. American Journal of Occupational Therapy. 2014; 68(2): 221–9. doi: 10.5014/ajot.2014.008938 PMID: 24581409

24. Barco PP, Baum CM, Ott BR, Ice S, Johnson A, Wallendorf M, et al. Driving errors in persons with dementia. Journal of the American Geriatrics Society. 2015; 63(7): 1373–80. doi: 10.1111/jgs.13508 PMID: 26140521

25. Marottoli RA, Cooney LM Jr., Wagner R, Doucette J, Tinetti ME. Predictors of automobile crashes and moving violations among elderly drivers. Annals of internal medicine. 1994; 121(11): 842–6. PMID: 7978696

26. Sims R, McGwin G, Allman R, Ball K, Owsley C. Exploratory study of incident vehicle crashes among older drivers. J Gerontol Med Sci 2000; 55(A): M22–M7.

27. Balcer L, Baier M, Cohen J, Kooijmans M, Sandrock A, Nano–Schiavi M, et al. Contrast letter acuity as a visual component for the Multiple Sclerosis Functional Composite. Neurology. 2003; 61(10): 1367–73. PMID: 14638957

28. Owsley C, McGwin G Jr. Vision and driving. Vision research. 2010; 50(23): 2348–61. doi: 10.1016/j.visres.2010.05.021 PMID: 20580907

29. Papa M, Boccardi V, Prestano R, Angelotti E, Desiderio M, Marano L, et al. Comorbidities and crash involvement among younger and older drivers. PLoS One. 2014; 9(4): e94564. doi: 10.1371/journal.pone.0094564 PMID: 24722619

30. Sperling RA, Aisen PS, Beckett LA, Bennett DA, Craft S, Fagan AM, et al. Toward defining the preclinical stages of Alzheimer’s disease: Recommendations from the National Institute on Aging-Alzheimer’s Association workgroups on diagnostic guidelines for Alzheimer’s disease. Alzheimers Dement. 2011; 7 (3): 280–92. doi: 10.1016/j.jalz.2011.03.003 PMID: 21514248