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Longitudinal Associations Between Changes in Physical Function and Driving Mobility Behaviors of Older Adults

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Abstract

Objectives—To examine time-varying correlations between multiple indices of physical function and driving mobility in older adults across five years.

Design—Longitudinal

Participants—Older drivers aged 65–91 ($M = 73.6 \pm 5.78$) who were randomly assigned to the no-contact control arm of the Advanced Cognitive Training for Independent and Vital Elderly study ($N = 598$).

Measurements—The driving mobility outcomes were self-reported driving space, driving exposure, driving frequency, and weekly mileage assessed at baseline, and first, second, third, and fifth follow-up visits. Physical functioning measures included grip strength, the Turn360 test, and self-reported physical function. Multilevel models examined relationships between changes in physical functioning and driving mobility outcomes over five years.

Results—Driving space and driving frequency decreased over time, especially for older individuals. Changes in physical function were positively related to changes in driving mobility after controlling for demographics, attrition, baseline cognitive function and visual acuity, and changes in general health. Patterns of associations varied depending on the specific physical function measure and mobility outcome.

Conclusions—The findings highlight the time-varying nature of the relationships between physical functioning and driving mobility. Further research is needed to fully understand dynamic associations between driving mobility and key components of mobility that vary over time.

Keywords

Driving Mobility; Older Drivers; Physical Functioning; Longitudinal; Time-varying

Over 80 percent of older Americans maintain a driver's license (1; 2), highlighting the continued importance of driving, both as a main mode of transportation and as a method to remain independent in the community (3). Older adults who limit or cease driving are more likely to suffer from a host of negative outcomes including increased risk of depression (4), nursing home entry (5), and mortality (6). Although clearly important, there have been relatively few detailed and multi-faceted longitudinal examinations of driving mobility outcomes in older adults. Driving mobility is broadly conceptualized as the extent to which one drives in his or her environment and is a continuum ranging from complete independence to drive where and when one wishes to full cessation of driving. There have been many measures of driving mobility in the literature including *driving space*, or how far beyond a certain radius a vehicle is driven (7); *driving exposure*, or exposure to driving situations such as driving at night (8); *driving frequency*, or number of driving days per week (9); and *miles* driven per week or per year (10). Given the importance of examining driving mobility from multiple constructs, this study will be the first to examine four driving mobility trajectories and how they relate to changes in three indices of physical function, an area that is poorly understood in the driving literature.

Currently, the majority of the driving mobility research has focused on demographic, sensory, cognitive, and health predictors. Older age (10-12), being a woman (13), and non-Caucasian race (13) have consistently been found as predictors for reduced driving mobility. Visual impairment, specifically poorer contrast sensitivity (10; 14), visual acuity (14), and peripheral vision (14), has also been extensively investigated and is predictive of less driving mobility. Persons who report diabetes, heart disease, or poorer health are also at greater risk for future driving mobility declines (9; 13; 15). Finally, worse cognitive performance, particularly with fluid process-based abilities such as speed of processing, divided attention, and executive function, is also associated with poorer driving mobility (7-9; 16; 17). Given that driving is a complex activity that involves consistent monitoring and planning of corresponding actions to a constantly changing environment, the relationships between poor vision, fluid processed-based cognitive abilities, health, and driving is not surprising. However, although physical functioning has been conceptually identified as a key contributing factor for maintained driving (18), inconsistent findings have resulted in investigators highlighting the need for further research examining the impact of physical functioning on driving outcomes (18).

Physical functioning can be broadly defined as the ability to carry out physical activities within the context of daily living (19). Although acknowledged as an ability needed to operate a vehicle safely (18), little research has examined the relationships between multiple components of physical functioning and driving mobility. In cross-sectional work, physical

functioning operationalized as lower foot extremity function, walking frequency per week, and exercise frequency did not significantly predict driving exposure, driving frequency, driving avoidance, or driving status (8; 20; 21). Conversely, other cross-sectional work that conceptualized physical functioning as joint rotational torque, reaction time for upper and lower body, and self-reported ability to walk a half mile, found that physical functioning predicted driving status (16) and reported driving difficulty (22). The discrepant findings between these studies, and the wide operationalization of physical functioning, clearly underscore the need for further work.

Turn 360 and grip strength are two easily administered measures of lower body and upper limb functioning that are predictive of health and disability outcomes (23; 24). At face value these measures represent physical abilities important for driving such as adequate strength for securing control of the steering wheel and sufficient lower leg strength and balance to maneuver in and out of the driver's seat. On an overarching level, an individual's perception of his or her physical functioning may also be an important factor for maintained driving mobility. Although all three of these physical functioning metrics impact driving mobility at a conceptual level, to the authors' knowledge no research has investigated how changes in these factors influence multiple driving mobility trajectories.

Finally, most information regarding changes in driving mobility among older persons are based on (a) cross-sectional studies, or (b) examination of longitudinal trajectories predicted by factors assessed at a single point in time (e.g., baseline visit). While limitations of cross-sectional work are generally known, the latter limitation has not been thoroughly discussed in the driving literature. Methods that use baseline metrics as predictors of outcome trajectories assume that relationships between outcomes and potential influences are stable across time, and that the predictor itself is stable across time. However, patterns of instability have been observed among factors predictive of mobility outcomes (e.g., self-reported health, cognition, and physical function), and have distinguished subgroups of older adults at risk for adverse functional and health outcomes (25; 26). Given these patterns of variability, it is unclear whether or not potential mobility influences maintain consistent relationships with driving mobility over time. It is possible that dissociations or increases in magnitude occur over time or within specific subgroups, but current methodologies do not account for this possibility. Thus, disparate results found in the literature may be at least partly attributed to a lack of knowledge about the time-varying correlations between driving outcomes and influential factors. A necessary next step in clarifying relationships between physical function and driving mobility is to explore changes in these relationships over time. This study aims to bridge a gap in the driving mobility and methodology literatures by examining time-varying associations in multiple indices of physical functioning and driving mobility over five years.

Methods

Participants

The present study utilized secondary data from the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) study, a six-site, longitudinal, randomized controlled trial that investigated the effects of cognitive training on cognitive, functional, and

health outcomes of 2,802 older adults. A detailed description of the ACTIVE study is detailed elsewhere (27). Current analyses were limited to participants randomized to the no-contact control condition who reported driving at baseline ($N = 598$). ACTIVE eligibility criteria included: 65 years of age or older; visual acuity $\leq 20/50$; intact mental status (i.e., Mini-Mental State Examination score ≥ 23); reported ability to perform activities of daily living; adequate communicative abilities; no reported health conditions likely to result in significant functional declines or two-year mortality; and no reported recent cognitive training. At baseline, participants in the analytic sample were an average of 73.6 years old ($SD = 5.78$), had 13.63 years of education ($SD = 2.68$), were predominantly composed of women (71.4%), and were predominately Caucasian (75.4%). All participants reported good to excellent health. Descriptive statistics are displayed in Table 1.

Study Design and Procedures

Participants randomized to the ACTIVE no-contact control arm visited field sites for all assessments, but received no intervention. In the present study, longitudinal associations across five years were examined between physical function and driving mobility, a secondary outcome assessed in ACTIVE. Self-reported driving mobility, physical function, and health were measured at baseline and at the first, second, third, and fifth annual visits. Performance-based physical function was assessed at all visits except the first annual. Demographic information was ascertained at the baseline visit, as was sensory and cognitive function.

Measures

Main Outcome Measures—Four self-reported driving habits outcomes were assessed with the reliable Driving Habits Questionnaire (DHQ) and the Life Space Questionnaire (LSQ; 28; 29). Consistent with previous research, drivers at baseline were operationalized as those who self-identified as having driven within the past 12 months and who would drive if needed; participants not meeting these criteria were coded as nondrivers (17). The questionnaire was repeated at years 1, 2, 3, and 5. Participants were coded as nondrivers at the wave they reported not driving and through the remainder of the study (incident nondrivers). For each of the driving outcomes, incident nondrivers were coded with a score of zero for that and each subsequent visit.

Driving Space: A driving space composite was comprised of six dichotomous questions from the LSQ assessing whether or not the participant had driven beyond a certain radius. The distances were assessed in relation to the previous seven days (beyond property, neighborhood, and town/community) and the past two months (beyond county/city, state, and region). Items were recoded and summed so that higher scores indicate greater driving space (range 0-6).

Driving Exposure: A composite for driving exposure was formed from summing eight dichotomous LSQ items pertaining to whether or not the participant had driven alone, made lane changes, turned left into oncoming traffic, driven in high traffic, at night, in the rain, merged with traffic, or driven during rush-hour in the last two months. Higher scores reflected more exposure to these driving situations (range 0-8).

Driving Frequency: The number of reported days driven in an average week (0-7) formed the driving frequency measure, with more days driven indicating higher driving frequency.

Weekly Mileage: Participants reported the number of miles driven in an average 7-day week.

Time-varying Predictors—Time-varying predictors included the primary physical function variables of interest (grip strength, turn 360 test, and self-reported physical function), as well as self-rated health. To facilitate interpretation of coefficients across measures, time-varying predictors were standardized at each time point by subtracting the baseline mean and dividing by the baseline standard deviation.

Grip Strength: Grip strength was measured using the Jamar hydraulic hand dynamometer (Lafayette Instruments, Lafayette, Ind., USA). The handheld dynamometer has been shown to be a reliable and valid instrument in older adult populations (30; 31). Two trials of grip strength, recorded in kilograms (kg) and rounded to the nearest whole number, were obtained for the participant's reported dominant hand using a standardized protocol. The grip strength test was waived if participants reported having hand or arm surgery during the last 3 months, tendonitis, recent worsening of pain, or arthritis. If performed, the two trials were averaged to yield a composite measure of grip strength, with higher scores reflecting greater strength.

Turn 360 Test: Lower limb functioning and balance was assessed with the Turn 360 Test (32). Participants were asked to turn in a complete circle while observers recorded the number of steps required to complete each turn. Scores were calculated by taking the average number of steps across two trials. Fewer steps indicated better performance.

Self-Reported Physical Functioning: Self-reported physical functioning was assessed using the physical functioning subscale of the SF-36 (33). Ten questions assessed how limited participants were in performing activities ranging from bathing or dressing to vigorous activities (rated on a 3-point scale from 1=limited a lot to 3=not limited at all).

General Health: Because changes in health status (e.g., disease development or progression) may affect upper and/or lower body physical function, self-rated health (rated on a 5-point scale from 1=poor to 5=excellent) was included as a time-varying covariate.

Time-invariant Covariates

Attrition: A dichotomous variable was created to account for attrition (non-dropouts = 0; dropouts = 1). Dropouts were participants without data at the five-year assessment.

Demographics: The following demographic variables were assessed at baseline and explored as potential confounders: age, self-reported years of education, race (non-Caucasian = 0; Caucasian = 1), and gender (female = 0; male = 1).

Vision: Far visual acuity was measured at baseline using the Good-Lite LD-10 chart in a Good-Lite model 600A light box. Wearing their usual far vision correction (e.g., glasses or

contact lenses), participants stood 10 feet away from the box with the chart at eye level. Scores ranged from 0 to 90 depending on the number of letters correctly identified (0 equates to a Snellen score 20/125; 90 to Snellen score 20/16).

Cognition: A composite representing baseline cognitive function across multiple domains was created by averaging the sample grand mean-centered and then standardized z-scores of the following measures: Letter Sets (34), Letter Series (35), Word Series (36), Rivermead Behavioral Memory Test Paragraph Recall (37), Hopkins Verbal Learning Test (HVL; 38), Rey Auditory-Verbal Learning Test (AVLT; 39), and the Useful Field of View (UFOV) Subtests 1-4 total reverse coded (40; 41). Participants' individual mean z-scores were used for missing items if no more than two items were missing at an assessment. If more than two items were missing, cognition was coded as missing. The composite had a Cronbach's alpha of .87 indicating good reliability.

Analyses

First, bivariate correlations and collinearity statistics were examined to assess multicollinearity among items comprising the cognitive composite, as well as all independent variables entered into multilevel models. No correlations or variance inflation factors exceeded the thresholds indicating multicollinearity (42); thus, all selected cognitive items were included in the cognitive composite and all proposed independent variables were retained for analyses. Next, chi-square and ANOVAs were used to examine attrition across the five year period. Main outcomes analyses employed multistep multilevel modeling (MLM) using the MIXED function in SPSS 22.0. MLMs, also known as random effects models, allow for examination of change over time, without many of the limitations associated with more traditional repeated measures statistical techniques (43). The random effect of time was scaled as number of months since the baseline assessment. Separate nested multilevel longitudinal models were estimated for each of the four driving mobility outcomes using restricted maximum likelihood method. Base models included all time-varying predictors, time-invariant covariates, as well as time*covariate interactions. Subsequent models included all time-varying predictors, time-invariant covariates, and significant time*covariate interactions; nonsignificant time*covariate interactions were excluded. For each outcome model, goodness of fit was evaluated by examining the reduction in Akaike's Information Criterion (AIC) and the Schwartz Bayesian Information Criterion (BIC) relative to an unconditional growth model that included time (month) as the only predictor.

Results

There were 598 participants included in the current analyses. Of these participants, 397 (66.4%) completed the five-year follow-up assessments. Participants who dropped out of the study were older, more likely to be male, non-Caucasian, performed worse on cognitive and Turn 360 assessments, reported poorer general health and physical function, and had less driving space, less driving exposure, and less driving frequency at baseline (p 's < .05), as compared to completers. Completers and non-completers did not differ on educational

attainment, vision, grip strength, or weekly mileage. Participant characteristics at baseline are displayed in Table 1.

Driving Space

After accounting for covariates, the average driving space across the five years was 3.72 ($SE = .13$). Changes in grip strength were positively associated with changes in driving space (estimate = .12, $p < .05$), such that for each kilogram decrease in grip strength there was a .12 decrease in driving space units. A positive relationship was also found between driving space and baseline cognitive function; for every unit of better cognitive function the sample averaged .04 units greater driving space ($p < .001$). Men also had greater driving space (estimate = .50, $p < .001$), reporting an average driving space .50 units greater compared to women. There was a negative effect of time (estimate = -.004, $p < .01$), such that on average driving space was reduced by approximately .50 units per year. An age*time interaction (estimate = -.001, $p < .01$) indicated that on average reductions in driving space over time were greater among older drivers.

Driving Exposure

After accounting for covariates, average driving exposure across the five years was 7.33 ($SE = .14$). Changes in Turn 360 (estimate = -.15, $p < .01$) and self-reported physical function (estimate = .18, $p < .01$) significantly predicted driving exposure changes. Each additional step needed to turn 360 degrees and for each unit decrease in physical function, there were .15 and .18 units of reduced driving exposure, respectively (Table 2). Each year of education was associated with nearly a half unit increase in driving exposure (estimate = .04, $p < .05$). As with driving space, there were significant negative effects of time (estimate = -.01, $p < .001$), such that driving exposure was reduced by approximately .12 units per year. An age*time interaction (estimate = -.002, $p < .001$) indicated that older participants reported greater reductions in driving exposure over time than did younger participants.

Driving Frequency

After accounting for covariates, participants averaged driving 5.85 ($SE = .18$) days each week across the five years. Similar to results found for driving exposure, changes in the number of steps required for Turn 360 performance (estimate = -.11, $p < .05$) and self-reported physical function (estimate = .24, $p < .001$) predicted changes in driving frequency (Table 2). Each additional step needed to turn 360 degrees was associated with .11 fewer days driven per week, and every unit decrease in physical functioning corresponded to approximately one quarter less days driven per week. Every year of education was associated with .07 additional days of driving (estimate = .07, $p < .05$). Men reported driving just over half a day more in an average week than women (estimate = -.60, $p < .01$). Age (estimate = -.01, $p < .001$) and age*time (estimate = -.001, $p < .001$) were associated with reduced driving frequency over time. Each decade of aging was associated with .1 fewer days of driving in an average week, and older participants reported greater decreases and driving frequency over time than did younger participants.

Weekly Mileage

After accounting for covariates, participants drove an average of 148.30 (SE=12.04) miles per week across the study period. Grip strength changes were positively associated with changes in weekly mileage (estimate = 12.02, $p < .05$), such that for every kg greater grip strength, an average of 12.02 additional miles were driven in an average week (Table 2). The same gender difference pattern held when examining weekly mileage over the study period; women drove approximately 62 fewer miles in an average week than men (estimate = -62.29, $p < .001$).

Discussion

This study is the first to examine the relationships between time-varying changes in multiple physical functioning indices and multiple driving mobility trajectories across five years. Consistent with some prior work (44), changes in physical function were positively related to driving behavior trajectories, after controlling for demographics, baseline cognitive function and visual acuity, attrition, and changes in general health. Specifically, changes in grip strength were associated with changes in driving space and number of miles driven in an average week, while changes in the number of steps and self-reported physical function were positively associated with driving exposure and driving frequency changes. Thus, declines in grip strength corresponded with decreases in the distance traveled away from the home and overall weekly mileage. Declines in lower limb mobility and balance, along with perceptions of physical functioning, co-occurred with reduced driving exposure and number of days driven in an average week.

Although the study design does not allow inferences of relationship directionality (e.g, uni- or bi-directional) or causation, examination of concurrent changes is important for several reasons. First, it is a necessary step in clarifying interrelationships between driving outcomes and factors that are susceptible to declines. This is especially important in older adult populations which have greater variability and can be more susceptible to relatively rapid declines as compared to younger or middle-aged adults. Developing a better understanding of how changes in factors such as physical health, cognition, sensory function, and physical function, relate to one another and to mobility over time will likely help identify mechanisms of adverse driving outcomes. For example, self-monitoring and beliefs about driving capacity have been posited as potential mediators between driving behavior and cognition, vision, and physical functioning (18). However, by definition self-monitoring implies an ongoing process providing opportunities for behavior adjustments at any point in time based on changes in functional status. In order to truly evaluate self-monitoring as a mechanism by which functioning influences driving behavior, analyses must account for changes in functioning as well as driving mobility. The practical utility of identifying mediators of these relationships is the potential to provide targeted avenues for interventions enabling maintained or enhanced driving mobility and safety.

Another clinically practical purpose for examining time-varying predictors of driving trajectories is to develop assessments aimed at distinguishing drivers at risk for future adverse driving outcomes such as mobility decrements. Ideally, performance trajectories would enable reliable prediction of changes in driving outcomes of interest, such that

clinical cut points could be established to identify those in need of intervention, and potentially discern those in need of more intensive or specific intervention based on their location on a given performance continuum.

Several attempts have been made at identifying performance-based test batteries to identify older drivers at risk for adverse driving events (44-47). While some overlap exists in specific performance assessments used in studies (e.g., Rapid Pace Walk test and neck rotation), there were also differences in the proposed batteries. This underscores a general need to develop a standard metric for operationalizing physical functioning, both for practical purposes and to facilitate interpretation of results across studies. The present analyses exemplify inconsistent results noted in much of the literature related to physical functioning and driving outcomes. Although physical function was related to all four mobility outcomes, patterns of associations varied across measures of physical function and specific mobility outcome. It is possible that more consistent results across studies would be observed with greater uniformity in the way physical function is operationalized.

The present study was the first, to the authors' knowledge, to examine time-varying associations of physical functioning and driving mobility, while controlling for changes in general health. Moreover, three measures of physical functioning standardized to the baseline mean were included in each mobility outcome model in order to facilitate comparisons within and between outcomes. Although this is an important step in developing a deeper understanding of interrelationships among physical performance measures and driving mobility outcomes, there are several limitations. First, only three physical functioning measures are available in the ACTIVE data set. Numerous physical functioning measures with variable levels of standardization, reliability, and validity are available, some of which may be more sensitive indicators of physical functioning as related to driving mobility; for example, time to reach peak force production at the ankle joint (44). An additional potential limitation is that driving mobility indices were self-reported and may not necessarily accurately capture true driving habits. Finally, the ACTIVE sample was very healthy and may not reflect the wider population thus limiting the generalizability to more diverse subgroups of older adults.

Future research should replicate these findings in less healthy subgroups of adults. Additionally, much work is needed in identifying and standardizing the most appropriate metrics for operationalizing physical functioning as it relates to driving outcomes. Finally, a central contribution of this study that should be extended in future work is the utilization of time-varying measures for investigations of changes in driving outcomes. Key contributing factors to driving mobility and safety, such as sensory, cognitive, health, and physical functioning, change greatly with age and need to be accounted for when examining driving outcomes.

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Table 1
Baseline Sample Characteristics (N=598)

	Mean	Standard Deviation	Range
Age	73.6	5.8	65.0 – 91.0
Education	13.6	2.7	6.0 – 20.0
Caucasian Race (%)	75.4	--	--
Male Gender (%)	28.6	--	--
Vision	73.7	11.6	31.8 – 90.0
Cognition	<0.1	5.2	-15.3 – 16.0
General Health	69.8	10.0	0.0 – 100.0
Attrition (% Study Completers)	66.4	--	--
Grip Strength	24.6	8.2	1.5 – 54.0
Turn 360	6.8	1.9	1.5 – 17.0
Self-Reported Physical Functioning	70.7	24.0	5.0 – 100.0
Driving Space	3.4	1.3	0.0 – 6.0
Driving Exposure	7.3	1.3	0.0 – 8.0
Driving Frequency	5.6	1.7	1.0 – 7.0
Weekly Mileage	108.9	113.3	0.0 – 800.0

Note: Greater Turn 360 scores indicate worse performance. Higher scores for vision, cognition, general health, grip strength, self-reported physical functioning, driving space, driving exposure, driving frequency, and weekly mileage indicate better function or driving mobility.

Table 2
Mixed Effects Modeling Results

	Driving Space Estimate (SE)	Driving Exposure Estimate (SE)	Driving Frequency Estimate (SE)	Weekly Mileage Estimate (SE)
Fixed Effects				
Intercept	3.72 (.13) ***	7.33 (.14) ***	5.85 (.18) ***	148.30 (12.04) ***
Grip Strength [‡]	.12 (.05) *	.11 (.06)	.07 (.07)	12.02 (4.78) *
Turn 360 [‡]	-.07 (.04)	-.15 (.05) **	-.11 (.05) *	.27 (3.78)
Self-Reported Physical Functioning [‡]	.08 (.05)	.18 (.05) **	.23 (.06) ***	4.23 (4.38)
Baseline Age	-.02 (.01)	-.01 (.01)	-.04 (.02) **	-1.76 (1.06)
Education	.04 (.02)	.04 (.02) *	.07 (.03) *	1.87 (1.87)
Caucasian Race	-.21 (.12)	-.05 (.13)	-.07 (.17)	-11.64 (11.97)
Women	-.50 (.14) ***	-.27 (.15)	-.60 (.19) **	-62.29 (12.65) ***
Vision	.01 (.00)	.00 (.01)	.01 (.01)	.06 (.40)
Cognition	.04 (.01) ***	.012 (.01)	<.01 (.02)	1.22 (1.12)
General Health [‡]	.002 (.04)	.011 (.04)	-.002 (.05)	6.06 (3.50)
Attrition (Study Completers)	.16 (.11)	.22 (.12)	.32 (.16) *	14.90 (10.62)
Time	-.004 (.00) **	-.01 (.00) ***	-.01 (.00) ***	-.19 (.12)
Age * Time	-.001 (.00) **	-.002 (.00) ***	-.001 (.00) ***	.004 (.02)
Random Effects				
Residual	.82 (.06) ***	.74 (.05) ***	.71 (.05) ***	5017.72 (336.74) ***
Intercept	.61 (.10) ***	.60 (.10) ***	1.71 (.16) ***	7646.39 (859.79) ***
Time	<.01 (<.001) *	<.01 (.00) ***	<.01 (.00) ***	.81 (.38) *

Notes:

 $p < .001$,

**
 $p < .01$,

*
 $p < .05$.

Greater Turn 360 scores indicate worse performance.

[‡] Grip strength, Turn 360, self-reported physical functioning, and general health are time-varying.

Outcome measures are driving space, driving exposure, driving frequency, and weekly mileage with higher scores indicating greater driving mobility.