Original Investigation

Longitudinal Relationships Among Visual Acuity, Daily Functional Status, and Mortality
The Salisbury Eye Evaluation Study

Sharon L. Christ, PhD; D. Diane Zheng, MS; Bonnielin K. Swenor, PhD; Byron L. Lam, MD; Sheila K. West, PhD; Stacey L. Tannenbaum, PhD; Beatriz E. Muñoz, MSc; David J. Lee, PhD

IMPORTANCE Determination of the mechanisms by which visual loss increases mortality risk is important for developing interventional strategies.

OBJECTIVE To evaluate the direct and indirect effects of loss of visual acuity (VA) on mortality risk through functional status changes among aging adults.

DESIGN, SETTING, AND PARTICIPANTS Prospective longitudinal study of a population-based sample of 2520 noninstitutionalized adults aged 65 to 84 years from September 16, 1993, through July 26, 2003, in the greater Salisbury area of Maryland. Participants underwent reassessment 2, 6, and 8 years after baseline. Mortality status was ascertained from linkage with the National Death Index through 2009.

EXPOSURES Results of VA testing and self-reported functional status based on activities of daily living (ADL) and instrumental ADL (IADL).

MAIN OUTCOMES AND MEASURE Mortality.

RESULTS Worse VA levels at baseline were associated with an increased the risk for mortality (hazard ratio [HR], 1.16 [95% CI, 1.04-1.28]; $P < .01$) through their effect on lower IADL levels at baseline. Declines in VA over time were associated with increased mortality risk (HR, 1.78 [95% CI, 1.27-2.51]; $P < .001$) by way of decreasing IADL levels over time. Participants experiencing the mean linear decline in VA of 1 letter on the Early Treatment Diabetic Retinopathy Study acuity chart per year are expected to have a 16% increase in mortality risk during the 8-year study exclusively through associated declines in IADL levels.

CONCLUSIONS AND RELEVANCE In this longitudinal study of older adults, VA loss adversely affected IADL levels, which subsequently increased the risk for mortality. Prevention of disabling ocular conditions, treatment of correctable visual impairment, and interventions designed to prevent the effect of visual impairment on IADL declines may all reduce mortality risk in aging adults.

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Author Affiliations: Department of Human Development and Family Studies, Purdue University, West Lafayette, Indiana (Christ); Department of Statistics, Purdue University, West Lafayette, Indiana (Christ); Department of Public Health Sciences, University of Miami Miller School of Medicine, Miami, Florida (Zheng, Tannenbaum, Lee); Dana Center for Preventive Ophthalmology, Wilmer Eye Institute, Johns Hopkins University School of Medicine, Baltimore, Maryland (Swenor, West, Muñoz); Bascom Palmer Eye Institute, University of Miami Miller School of Medicine, Miami, Florida (Lam, Lee).

Corresponding Author: Sharon L. Christ, PhD, Department of Human Development and Family Studies, Purdue University, Fowler Memorial House, 1200 W State St, West Lafayette, IN 47907-2055 (slchrist@purdue.edu).

Improving the nation's access to ocular health care is important, given that visual impairment (VI) is associated with a variety of functional and health outcomes, including increased risk for mortality.[1-14] Visual impairment has significant negative effects on physical and psychosocial health,[13,15-40] but the specific mechanisms and pathways by which VI increases overall mortality remain unclear.

Several investigators have proposed mechanisms by which VI may increase overall mortality, including increased physical disability, reduced mental well-being, and severe depressive symptoms.[13,14,40-42] These analyses, however, are limited by a lack of information on changes in visual acuity (VA) and changes in functioning as people age.

Using longitudinal population-based data collected during 4 assessment periods and a total of 8 years, a previous study[43] found that increases in VA loss over time are related to increased difficulties in instrumental activities of daily living (IADL) in men and women and increased difficulties in activities of daily living (ADL) for men only. Activities of daily living are necessary in fundamental daily function (eg, bathing, dressing, eating), whereas IADL are measures of the degree to which an individual lives independently in the community (eg, telephone use, shopping, housework).[44,45] To elucidate the relationship between VA loss and increased mortality, the present study used data from the Salisbury Eye Evaluation study to examine whether and to what extent loss of VA increases overall mortality through its effects on changes in ADL and IADL over time.

Methods

Study Population and Design

The Salisbury Eye Evaluation is a population-based study of age-related eye diseases, VI, and functional status of noninstitutionalized residents aged 65 to 84 years.[46] This project was approved by the University of Miami and the Johns Hopkins School of Medicine institutional review boards. Written informed consent was obtained from all participants. A detailed description of the sampling procedure is given in the eMethods in the Supplement.[46,47] Eligible participants had to be able to travel to the clinic for vision tests and to score more than 17 on the Mini-Mental State Examination.[48] Eligible participants underwent a 2-hour in-home interview followed by a 4- to 5-hour examination in a clinic. Of those who were eligible, 64.51% participated. The initial cohort included 2520 participants. Reassessments took place 2, 6, and 8 years later. In total, 2240 persons participated in the second round (1995-1997), 1504 in the third round (1999- 2001), and 1250 in the fourth round (2001- 2003), with more than half the loss between rounds due to death. A linkage with National Death Index (NDI) was performed for the entire study population in 2011, with mortality follow-up through December 31, 2009. The mortality follow-up identified 1622 all-cause deaths (64.4%).

Of the 2520 initial study participants in the first round, 42.1% were men, 73.6% were white, and 26.4% were black. The highest educational level attained was less than high school for 51.5% and more than high school for 28.1%. Detailed information on sociodemographic and health-associated characteristics of the study population can be found in eTable 1 in the Supplement.

Measures

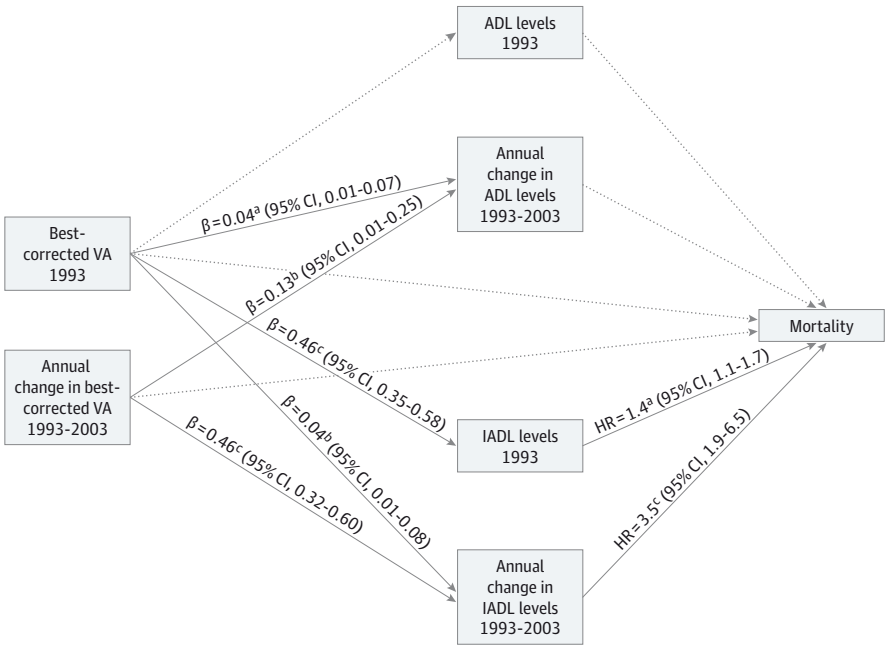
Best-corrected VA was assessed using the Early Treatment Diabetic Retinopathy Study (ETDRS) chart, and ETDRS refraction was performed on participants with VA of worse than 20/30.[49] Best-corrected binocular distance VA was converted to logMAR units. Functional status of ADL and IADL were measured using standardized validated questionnaires.[44,45] Assessments of ADL included difficulties with the following items: (1) getting out of bed or a chair; (2) dressing oneself; (3) bathing or showering; (4) using the toilet; and (5) feeding oneself. Assessments of IADL included difficulty with the following items: (1) using the telephone; (2) doing light housework or light yard work; (3) doing heavy housework or heavy yard work; (4) preparing meals; (5) managing money; and (6) shopping for personal items such as medicines. Each question started with the following: "By yourself, that is, without help of another person or special equipment, do you have any difficulty…?" Each question had response options of no difficulty, a little difficulty, some difficulty, a lot of difficulty, and unable to do this for health or physical reasons. We used confirmatory factor analysis and associated model fit statistics to validate the items in the IADL and ADL scales.[43] Functional status scores of ADL and IADL were constructed by summing the 5 and 6 items, respectively, at each assessment and then dividing by a factor of 10.

Control variables included demographics, health behavior variables, physical health conditions, and severe depression. A standardized form was used to query all participants about demographics (eg, age, sex, race, formal educational level) and medical history of physical health conditions. All control variables used in the models were measured at baseline assessment. Educational level was measured as the highest grade completed and ranged from 0 to 17 years. The age and educational variables were centralized and rescaled by a factor of 10. Medical history included 15 medical conditions that were self-reported responses to the question, "Has a doctor ever told you that you have…?" The 15 conditions included diabetes mellitus, stroke, heart disease, hypertension, cancer, asthma, arthritis, angina, back problems, a broken hip, congestive heart failure, claudication, emphysema, Meniere disease, and Parkinson disease. Severe depression was assessed using the Severe Depression subscale of the 28-item General Health Questionnaire.[49] Health behavior–related variables included questions on smoking and alcohol use (current, past, or never). Height and weight were measured and categorized as normal (reference body mass index [BMI; calculated as weight in kilograms divided by height in meters squared], 18.5 to <25.0), underweight (BMI, <18.5), overweight (BMI, 25.0 to <30.0), obese (BMI, 30.0-35.0), or very obese (BMI, >35.0).

Statistical Analysis

We applied a multistep, theoretically grounded modeling process in a structural equation modeling framework, which is described in greater detail in the eMethods in the Supplement.

Figure. Final Model of Trajectories of Activities of Daily Living (ADL) and Instrumental ADL (IADL) as Mediators of the Relationship of Visual Acuity (VA) Trajectories, Covariates, and Mortality



Dotted arrows represent pathways that are not statistically significant at α = .05; solid arrows, statistically significant pathways. All pathways control for age, sex, race, educational level, smoking status, alcohol use status, obesity, severe depression, and 15 health conditions (listed in the Measures subsection of the Methods section). Boxes represent variables for which VA at baseline and VA changes over time are independent variables predicting mortality directly and indirectly. The model includes 5 equations (4 for the mediators and 1 for mortality). Parameter estimates from the system of equations were estimated simultaneously. HR indicates hazard ratio.

[a] $P < .01$.

[b] $P < .05$.

[c] $P < .001$.

Variables measuring baseline levels and changes over time (ie, trajectories) in levels of VA, ADL, and IADL were obtained for each study participant from ordinary least squares regression models. Cox proportional hazard regression was used to estimate effects of the trajectory variables on mortality, and linear regression was used to estimate the effects of VA trajectory variables on ADL and IADL trajectory variable mediators.

To evaluate the effects of VA trajectories on mortality under different controls, we estimated 4 mortality models where groups of covariates were added in a hierarchical fashion. In model 1, the effects of baseline VA levels and VA changes on mortality were estimated while controlling for demographic variables such as age, sex, and race. In model 2, health behavior variables (smoking, alcohol use, and BMI) were added. In model 3, the 15 self-reported medical conditions and severe depression were added as control variables. A final structural equation model (model 4) included ADL and IADL trajectories (levels and changes) as mediators of the relationship among VA trajectories, covariates, and mortality (**Figure**). The VA, ADL, and IADL trajectories and the covariates were all hypothesized to affect mortality directly. In addition, VA trajectories and covariates affected mortality indirectly through ADL and IADL trajectories. Therefore, the ADL and IADL trajectories served as mediators for the relationships between the VA trajectories and mortality.

In model 4, multiple equations were estimated simultaneously using a maximum likelihood estimator with robust standard errors. Indirect (mediated) effects were calculated using a product of coefficients method by multiplying the 2 parameter estimates involved in the mediation relationship.[50] For example, the effect of VA levels at baseline on IADL levels at baseline was multiplied by the effect of IADL levels at baseline on mortality. The new estimate was exponentiated to obtain the hazard ratio (HR) for the indirect effect. Hazard ratios for total effects were calculated by taking exponentiation of the summed direct and indirect coefficients. Standard errors for indirect and total effects were obtained using the delta method.[51] Hazard ratios of VA trajectories from the 4 mortality models were presented side by side (eTable 2 in the Supplement); only results from model 4 are presented below. We completed descriptive and model-based analyses using commercially available statistical packages (SAS, version 9.2[52,53] and Mplus 7,[54] respectively).

Results

Loss of VA and difficulties with ADL and IADL all increased as this population aged (**Table 1**). The mean annual decline in best-corrected VA was 0.02 logMAR U, an annual loss of nearly 1 letter on the ETDRS VA chart or close to 1 line during 5 years. Difficulties with ADL increased a mean of 0.013 raw U (or 0.16 standardized U), and difficulties with IADL increased a mean of 0.027 raw U (0.27 standardized U) every year. These annual changes in ADL and IADL cumulated during the 8-year period are equivalent to increasing 1 point on each of the 5 items in the ADL scale (eg, from a little difficulty to some difficulty) and more than 2 points on each of the 6 items in the IADL scale.

In our final, comprehensive model, VA levels at baseline (HR, 0.89 [95% CI, 0.67-1.18]; $P = .41$) and VA change over time (HR, 1.95 [95% CI, 0.58-6.50]; $P = .28$) did not directly predict mortality (**Table 2** and Figure). As shown in eTable 2 in the Supplement, baseline ADL levels (HR, 1.20 [95% CI, 0.86-

Table 1. Baseline Levels and Changes in Study Outcomes

Measures	Mean (SD)	
	Baseline Level	Annual Change
VA, logMAR U	0.01 (0.19)	0.02 (0.05)
ADL, raw U[a]	0.60 (0.23)	0.01 (0.08)[b]
IADL, raw U[c]	0.82 (0.39)	0.03 (0.10)[d]

Abbreviations: ADL, activities of daily living; IADL, instrumental ADL; VA, visual acuity.

[a] Indicates a scale range of −0.31 to 1.70.

[b] Indicates a mean 1-point increase on every item during the 8-year period.

[c] Indicates a scale range of −0.90 to 3.00.

[d] Indicates a mean 2-point increase on every item during the 8-year period.

Table 2. Effects of VA on Mortality Through Mediated Pathways in the Final Model

Pathway Type	HR (95% CI)
Direct effects	
Best-corrected baseline levels	0.89 (0.67-1.18)
Best-corrected change	1.95 (0.58-6.50)
Indirect effects	
VA levels through IADL levels	1.16 (1.04-1.28)
VA levels through IADL change	1.06 (1.00-1.12)
VA levels through ADL levels	1.00 (0.99-1.02)
VA levels through ADL change	1.00 (0.97-1.03)
VA change through IADL change	1.78 (1.27-2.51)
VA change through ADL change	1.00 (0.91-1.11)
Total effects	
Direct and indirect VA levels through IADL levels	1.02 (0.78-1.28)
Direct and indirect VA change through IADL change	3.47 (1.07-11.31)

Abbreviations: ADL, activities of daily living; HR, hazard ratio; IADL, instrumental ADL; VA, visual acuity.

1.66]; $P = .28$) and changes in ADL (HR, 1.01 [95% CI, 0.45-2.22], $P = .99$) also did not predict mortality. However, baseline IADL levels and changes in IADL levels were significant predictors of mortality even after controlling for all covariates and VA and ADL baseline levels and changes over time. A 1-U increase in baseline IADL score was associated with an increased risk for death (HR, 1.36 [95% CI, 1.10-1.70]; $P < .01$). Moreover, for a mean increase of 1 U in the annual rate of IADL score, the hazard of death was nearly 3.5 times that of individuals with stable IADL levels over time (HR, 3.49 [95% CI, 1.89-6.47]; $P < .001$). In other words, individuals who experienced increasing difficulty with IADL by the mean amount (0.027 per year) had an increase in mortality hazard that was 3% greater annually and 31% greater during the 8-year study period than individuals with a stable IADL difficulty level.

Although VA changes did not affect mortality directly in the final model, they affected mortality indirectly through increases in IADL difficulties. The indirect effect of lower VA levels at baseline on mortality through its effect on IADL levels at baseline was an HR of 1.16 (95% CI, 1.04-1.28; $P < .01$). The indirect effect of decreasing VA over time on mortality through its effect on decreasing IADL over time was an HR of 1.78 (95% CI, 1.27- 2.51; $P < .001$). Participants experiencing the mean linear decline in VA of 1 letter on the ETDRS acuity chart per year are expected to have a 16% increase in mortality risk during the 8-year study exclusively through associated declines in IADL levels. The total (direct plus indirect through increases in IADL difficulties) effect of VA declines on mortality risk was substantial (HR, 3.47 [95% CI, 1.07-11.31]; $P < .05$) (Table 2).

Table 3. Nonlinear Effects of VA on Mortality Through IADL Mediators

Mortality Effect	HR (95% CI)
Baseline VA levels through IADL levels	
20/16	0.99 (0.98-1.00)
20/20	1.00 (1.00-1.00)
20/40	1.03 (1.01-1.06)
20/50	1.05 (1.01-1.09)
20/80	1.08 (1.02-1.15)
20/200	1.18 (1.05-1.32)
Annual change in VA through IADL change	
No change	1 [Reference]
Lose 1 letter	1.01 (1.00-1.02)
Lose 3 letters	1.03 (1.01-1.06)
Lose 5 letters	1.06 (1.02-1.10)
Lose 7 letters	1.09 (1.04-1.15)

Abbreviations: HR, hazard ratio; IADL, instrumental activities of daily living; VA, visual acuity.

We found evidence of nonlinear relationships between VA and ADL, IADL, and mortality. Nonlinear indirect effects of VA through IADL levels were significant at all levels of VI at baseline and all degrees of decline in VA over time (**Table 3**). For example, participants with baseline VA levels of 20/80 had an 8% increased risk for mortality (HR, 1.08 [95% CI, 1.02-1.15]; $P = .005$). We found some evidence of a direct nonlinear relationship between VA and mortality, but only at extreme levels. For example, persons who lost a mean of 7 letters of VA per year directly increased their mortality hazard by 18% (HR, 1.18 [95% CI, 1.01-1.39]; $P = .04$).

Discussion

Many of the aforementioned studies on VA and mortality include an assessment of VA levels at only 1 time. Consistent with these studies,[1-14] we found evidence that baseline levels of VI are associated with an increased risk for mortality after adjustment for potential confounders (models 1 and 2 [eTable 2 in the Supplement). However, the Salisbury Eye Evaluation study was designed to monitor change in functional limitations carefully during 4 periods in addition to monitoring change in VA during the same time period. Therefore, we were able to evaluate the relationships between the dynamic aging processes, including changes in VA, and daily functioning. In addition, we evaluated the mechanisms by which changes in VA affect mortality. We found that declines in VA adversely affect changes in IADL that, in turn, predict mortality. After including IADL as a mediator, baseline VA levels and VA changes

did not affect mortality risk directly. Therefore, VA processes affect mortality almost entirely through the effect on IADL processes.

The present findings confirm that declining IADL levels are a potent predictor of mortality and that the deleterious effects of declining VA on mortality appear to operate, in a large way, through these reductions in IADL levels. This finding suggests that the adverse effects of declining VA on health are somewhat insidious in nature because researchers have been unable to study the complex interplay between changes in VA and IADL and the aging process.

The mechanisms by which declining IADL levels increase mortality are likely to be multifactorial. Declining IADL levels are associated with an increased risk for cognitive decline and dementia[55,56] and declines in motor performance.[57] Declining IADL levels also have profound psychosocial effects, including loneliness, depression, and social isolation, which have all been implicated in excess mortality.[58-62] Furthermore, these outcomes may lead to a cascade of behavioral effects that accelerate risk for decline and death. For example, lonely older adults are less likely to engage in physical activity,[63] which is negatively related to mortality.[64]

In the present study, the link from ADL to mortality is not detected in our models that also include IADL levels. Stronger associations between IADL and mortality relative to ADL and mortality have been reported in community-based studies.[65,66]

In our study, the direct pathway between ADL and mortality is significant when IADL levels are not included in the model (eMethods and eFigure in the Supplement). One possible reason for this finding is that less variability in ADL than in IADL was found in the Salisbury Eye Evaluation population. Also, some participants were ineligible for follow-up because they had moved into institutional settings such as nursing homes. Variability in our ADL measure may have been greater had we been able to assess functional status in this subset of participants, given that difficulties with ADL are an important predictor of institutionalization.[67]

Study Implications

Our findings have multiple implications. First, these findings reinforce the need for the primary prevention of VI. Primary prevention can be accomplished by addressing the risk factors that led to disabling ocular conditions and through preventive ocular care. For example, the obesity epidemic in the United States has led to an increase in the prevalence of diabetic retinopathy.[68] More effective strategies targeting obesity have clear implications for ocular health. Moreover, the early detection of disabling eye diseases is suboptimal in the US health care system, leading to otherwise preventable VI.[69] Finally, many Americans live with VI that is correctable through the proper fitting of glasses or contact lenses.[70,71]

A second implication of our findings suggests that when uncorrectable VI is present, helping affected individuals maintain robust IADL is important. For example, persuading older adults with VI to be more physically active can help to preserve functional status. Lee et al[72] found that targeted interventions such as physical activity may improve functioning over time; this finding may be particularly true for those living with VI, but clinical trials supporting this hypothesis have not been published.

More than 20 years ago, Fried and Bush[73] proposed that 1 major preventive health care objective in the elderly is the prevention of disability and premature mortality by postponing functional declines such as those reflected in the assessment of IADL. Our findings support their conceptual model that impairment leads to disability (eg, declining IADL), followed eventually by handicap (eg, declining ADL) and premature mortality. To interrupt this downward health spiral, Fried and Bush[73] proposed that the critical point for effective intervention is when impairment is first diagnosed. Using data from the National Long-term Care Surveys linked with Medicare claims data, Sloan and colleagues[74] reported that the probability of individual IADL declines in grocery shopping, meal preparation, doing laundry, and doing light housework was reduced 5% to 10% per each additional annual eye examination visit during a 5-year period.

Results of the present study therefore reinforce the important gatekeeper role that eye care providers can serve by identifying and referring patients with VI to relevant support services.[75] Available resources for maintenance and improvement of ADL and IADL for individuals with VI include centers that provide independent living skills and support for low VA (eg, Lighthouse for the Blind) and specialized fitness and life-enhancing organizations (eg, Beyond Blindness Institute).

Finally, the Affordable Care Act[76] will result in an estimated 30 to 33 million newly insured adults by 2016.[77] Although planned state-specific essential benefits packages will not mandate comprehensive vision benefits for adults,[78] this increase in the number of insured will nevertheless lead to increased detection and treatment of vision-associated ocular conditions such as diabetic retinopathy, macular degeneration, and cataract.[79] The present findings also suggest that policymakers may wish to undertake new cost-benefit analyses to consider adding comprehensive vision benefits for adults in future benefit packages.[80] These analyses should take into consideration the effect that regular eye care examinations may have on delaying the onset of IADL impairment,[74] its potential to reduce, delay, or prevent the transition into expensive institutional care settings,[31,81] and its associated effects on increased survival.

Study Limitations

Although our models provide stronger tests of association by controlling for all static, within-person characteristics, they do not control for unobserved covariates that may change over time.[82,83] For example, we are unable to estimate the model using time-varying assessments of health conditions and therefore we controlled for baseline levels only. Mortality linkage with the National Death Index is probabilistic in nature, and therefore some misclassification of mortality status might result.[84] However, such misclassification is likely minimized by the careful collection of name, Social Security number, date of birth, and other identifiers used in the linkage. Although driving ability has been shown to be correlated with VA-related functioning, driving ability was not included in the IADL scale. Finally, this study was based on data from 1993 through 2003, which may not reflect the current medical conditions and care patterns of US adults aged 60 to 80 years.

Conclusions

This longitudinal study of community-residing older adults documented the increased risk for mortality associated with lower levels and declines in best-corrected VA through its adverse effect on IADL. Additional research is needed to confirm this pathway and to understand better how increasing VI leads to these reductions. Interventions designed to reduce the functional burden associated with declining vision are also needed.

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Study concept and design: Christ, West, Tannenbaum, Lee.
Acquisition, analysis, or interpretation of data: Christ, Zheng, Swenor, Lam, Muñoz, Lee.
Drafting of the manuscript: Christ, Zheng, Swenor, Lam, Tannenbaum, Lee.
Critical revision of the manuscript for important intellectual content: Christ, Lam, West, Tannenbaum, Muñoz, Lee.
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