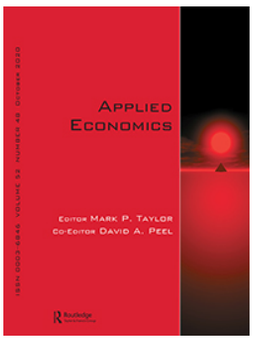

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A CBA of corrective lenses, including the benefits for reducing the symptoms of dementia

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ABSTRACT

We carried out a CBA of corrective lenses (CLs) that had direct benefits, and included indirect benefits working through a reduction in dementia symptoms. The benefits took the form of a reduction in mortality that was expressed in monetary terms by using the value of a statistical life (VSL) methodology. The indirect benefits consisted of CLs first lowering dementia symptoms and in this way reducing mortality. Estimation of the impact on mortality of CLs and dementia symptoms was carried out using a random effects Logit regression on a large national panel data set provided by the National Alzheimer's Coordinating Centre. The effect of CLs on dementia symptoms was estimated by a fixed effects regression. The VSL figure came from the literature. The net-benefits overall were positive and large, and even positive just from the indirect dementia benefits alone.

KEYWORDS

Corrective lenses; dementia; cost-benefit analysis; value of a statistical life

JEL CLASSIFICATION

I12; J14

I. Introduction

Presbyopia is an age-related condition that involves a loss of elasticity of the lens of the eye that results in the loss of the eye' ability to see near objects. In 2000 there were 1.4 billion people with presbyopia, and this increased to 1.8 billion in 2015. Of the 1.8 billion, 826 million persons had vision impairment because they had no, or inadequate, vision correction, VC. If we add to those with near-sighted vision, those with long to near distance vision loss, and this includes almost everyone aged 55 years and over, then there were over 3 billion people with some level of refractive error (hyperopia, myopia and astigmatism), Fricke et al. (2018).

The global costs generated by those with vision impairment not having VC, in terms of the loss of production that results, was estimated by the WHO to be 202 billion USD annually, Fricke et al. (2012). This raises the question whether it would be socially worthwhile to provide VC to those with uncorrected vision impairment, which is around 10% of the world's population. To begin to answer this question, we carry out a cost-benefit analysis (CBA) of vision correction in the form of corrective lenses (CLs) in the US to see if they are socially worthwhile for older adults.

Dementia, like vision loss, is also an increasing function of ageing. In 2018, an estimated 5.7 million Americans are living with Alzheimer's, the major cause of dementia. Of these people, 5.5 million are age 65 or over, which means that 200,000 individuals are under 65. Since Alzheimer's increases with age, and the population of the US is ageing rapidly, one can expect the numbers to increase greatly over time, at the rate of one every 65 seconds (Alzheimer's Association 2018).[1]

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[1]What is classed as 'Alzheimer's' in the US has changed over time. The 1984 guidelines focused on cognitive impairment symptoms. However, the 2011 guidelines requires there to be brain pathology, even if there are no symptoms. Thus, the 2011 guidelines includes those with brain pathology without symptoms, and excludes those with symptoms if they do not have the brain pathology. The number of people newly excluded from the 2011 classification were roughly the same number as those newly included, which means that the Alzheimer's numbers are comparable over time. We continue to rely on a definition of dementia based on cognitive symptoms diagnosed by a clinician, rather than a definition of dementia defined by brain pathology, because our NACC data set continues to use this definition and there is no treatment currently available that can reduce brain pathology.

Because pharmaceutical medicines have had limited success so far, there is a need to identify non-pharmacological interventions that can ameliorate dementia. For examples of non-pharmacological dementia interventions, see Brent (2018a, 2018b, 2019). One of the most important symptoms of late-life dementia, especially those with Alzheimer's disease, is the person's lack of orientation. As poor vision can lead to disorientation, the loss of vision can be a primary contributor to dementia. Anything that can improve vision, such as CLs, would therefore be another way of preventing the development of dementia (Rogers and Langa 2010). We therefore hypothesize that reducing dementia symptoms could be an additional category of benefits to include in any CBA of CLs for older adults, and we include them together with the other main benefits that CLs bring.

We call the main benefits from CLs the direct benefits, and the benefits from reducing the symptoms of dementia the indirect benefits. Any costs of CLs would need to be compared with both categories of benefits. In CBA practice, it is usual for the costs of any intervention to be valued by market prices. The main challenge in CBA is to decide on a methodology for valuing the benefits. For both the direct and indirect benefits, mortality risk can be used as the outcome measure, and in this context the valuation of that risk, which is the value of a statistical life (VSL), is the relevant benefit methodology.

The justification for focusing on the probability of dying as the outcome measure for CLs is that, for older adults, poor vision can lead to deaths from car accidents and from increased falls. In a study of 10,000 California drivers, those with abnormalities in both eyes had twice the accident rate of those with abnormalities in one eye, or had normal vision, Johnson and Keltner (1983). Falls are the leading cause of accidental injury and death among older adults. Vision motion perception is an essential function in maintaining balance, Saftari and Kwon (2018). Individuals with dementia can be expected to have problems maintaining balance and so dementia is a risk factor for falls, Stenhagen et al. (2013).

In this article, we will therefore be carrying out a CBA of CLs including both direct and indirect benefits. Both the effect of CLs on dementia, and the effects of CLs and dementia on mortality risk, will be estimated using data from the National Alzheimer's Coordinating Centre (NACC). The estimate of the VSL will be taken from the literature.

In the next section, we explain the methodology behind the benefits of CLs that we will be using. Section III presents the estimation framework for the two types of benefits. Section IV covers the data source and the specifications of the key variables that are in that data source. This is followed by a description of all the variables used in our study and the data summary. The statistical estimation results are in section V1 and the benefit estimates based on those estimation results are in Section VII. Section VIII gives the cost estimates and, combined with the benefits estimates, the net-benefits are calculated. The sensitivity analysis is in Section IX and Section X gives the summary and conclusions, which mentions some policy implications of our results.

II. The method for estimating the benefits of corrective lenses

The benefit method that we use for the CBA is based on the expected value of a statistical life E(VSL):

$$B = E(VSL) = \pi \times \text{VSL} = \pi \times \overline{VSL} \qquad (1)$$

where π is the probability of dying that is avoided by *CL* and the VSL is determined independently by a person's labour risk-wage trade-off. *CL* affects π directly and also indirectly through the dementia symptoms (D) they reduce:

$$\pi = \pi(D(CL), CL)) \qquad (2)$$

The contribution of CL to benefits is therefore given as:

$$\frac{dB}{dCL} = \frac{d\pi}{dCL}\,\overline{VSL} = \left(\frac{\partial \pi}{\partial D}\,\frac{\partial D}{\partial CL} + \frac{\partial \pi}{\partial CL}\right)\overline{VSL} \qquad (3)$$

where we expect $\frac{\partial \pi}{\partial CL} < 0$, $\frac{\partial \pi}{\partial D} > 0$ and $\frac{\partial D}{\partial CL} < 0$. This means that both of the contributions of *CL* to benefits are expected to be positive, as *CL reduces* both the probability of dying and the symptoms of

dementia, which are the two negative components. From Equation (3) we define:

$$\text{Direct benefits}: \left(\frac{\partial \pi}{\partial CL}\right)\overline{VSL} \tag{3a}$$

$$\text{Indirect benefits}: \left(\frac{\partial \pi}{\partial D}\frac{\partial D}{\partial CL}\right)\overline{VSL} \tag{3b}$$

III. Estimation framework

The $\overline{VSL}$ amount in Equations (3a) and (3b) will be taken from the CBA literature. To estimate the other three components, we specify two regression equations. Since we will be using panel data for the estimation, we will use for all variables the subscripts *ij*, where *i* denotes the client involved, and *j* stands for the visit number.[2]

The effects of corrective lenses on mortality

For the first regression, the dependent variable is the probability of dying π. The independent variables are *D* and *CL*, together with a set of controls *X specified* in the literature to be the main determinants of the mortality of older adults. Therefore, we have for the first regression (using a panel data, two-way, random effects construction):

$$\pi_{iv} = \alpha_0 + \alpha_1 D_{iv} + \alpha_2 CL_{iv} + \alpha_j X_{iv} + \varepsilon_i + \varepsilon_v + \varepsilon_{iv} \tag{4}$$

where the α coefficients are constants, ε_i and ε_v are the client- and visit-specific random error terms, and ε_{iv} is the overall random error term.[3] From Equation (4), we have:

$$\frac{\partial \pi}{\partial D} = \alpha_1 \text{ and } \frac{\partial \pi}{\partial CL} = \alpha_2 \tag{5}$$

Since the dependent variable is a probability, we will use a Logit equation for estimation. For the panel data that we will be using, fixed effects models cannot be used for discrete dependent variables.[4] This leaves us with a random effects model as the feasible estimation technique. Note that for Equation (4), there can be no reverse causation for mortality on our vision variables *CL* and *D*. Thus, our identification strategy for the first regression is mainly to include a large number of control variables in the equation itself. This helps reduce the possibility that there will be a variable left in the error term that would cause both mortality and the vision variables to be spuriously related, causing the regression coefficients estimates α_1 and α_2 to be biased.

The selection of the controls

More than 75% of the gains in life expectancy today are realized after 65 years of age (Eggleston and Fuchs 2012). Our sample of older adults with their behaviour and characteristics is therefore highly relevant for examining the possible determinants of mortality. We will assign variables to categories that have been identified by the Economics demographic literature to be some of the main determinants of adult mortality, see for example Cutler, Deaton, and Lleras-Muney (2006), Shaw, Horrace, and Vogel (2005), and Hummer, Rogers, and Eberstein (1998). As the demographic variables, we have age, race and gender; for nutrition we have height and birth month; and for medical reasons we use BMI, smoking behaviour and depression. One weakness of our data set is that we do not have a public health variable, such as types of immunization. But, as an environmental or locality proxy, we can use the type of residence housing a client has, seeing that the type of housing can affect mortality outcomes if illnesses are contagious.

The effect of corrective lenses on dementia

For the second regression, the dependent variable is dementia *D*, and *CL* is the main independent variable. We also include other independent variables as controls that are known from our previous

[2]It is more usual for data in a panel to use *it* as the identifying subscripts. But, in our data set, there was a strong overlap between the visit number *j* and the year *t*, which enables us to use *ij* as the unique identifying subscript (for many clients, more than one visit took place in any given year).
[3]In a random effects framework, the estimated coefficients α_1 and α_2 will be unbiased only if the error terms ε_i and ε_v are assumed to be uncorrelated with all the independent variables and controls in Equation (4).
[4]This is the so called 'incidental parameters problem', Wooldridge (2002).

CBAs to causally affect dementia: ageing A and hearing aids HAs.[5]

The dependent variable for this second equation is continuous. Therefore, we can use a fixed effects model on our panel data to try to control for unobservable variables that may be in the error term that would cause the coefficient on CL to be biased. What is fixed from a client visit is many unobserved characteristics of a clinic visit v (such as, the behaviour of the clinician interviewing the client) or the unobserved characteristics of a client i's personality (e.g., being passive or aggressive). Since these unobserved characteristics do not vary by visit or client, they cannot influence the dependent variable; so there cannot be missing variables that determine both D and CL. The estimated impact of CL on D would then only be because CL was causal. The fixed effects model is therefore our identification strategy for the second regression equation.

The way the fixed effects model is implemented is by including both a set of visit dummy variable intercepts β_v and a set of individual dummy variable intercepts β_i in the regression equation. Because of this, the estimation method is called a two-way, fixed effects model. The specification of the second regression would then be:

$$D_{iv} = \beta_0 + \beta_1 CL_{iv} + \beta_2 A_{iv} + \beta_3 HA_{iv} + \beta_v + \beta_i + u_{iv} \quad (6)$$

where the β coefficients are the regression parameters to be estimated and u_{iv} is the random error term.

For panel data, the main estimation alternative to the fixed effects model is the random effects model that treats the individual and visit dummies as random variables. A random effects model could be applicable to our data set because new individuals were added in successive sample rounds. Thus, sample characteristics could vary across individuals and by visit number. To test whether a fixed effects model is more appropriate than a random effects model, the Hausman test can be used. This test compares the estimates of the coefficients obtained from the two estimators. The null is that there is no difference between the two sets of coefficients. If the null is rejected, the fixed effects estimates are chosen because their estimates are known to be consistent, see Wooldridge (2002). Because in all our estimations the Hausman null is rejected, Equation (6) will be the specification we will be using.

From Equation (6) we obtain:

$$\frac{\partial D}{\partial CL} = \beta_1 \quad (7)$$

It is through Equations (5) and (7) that we will obtain our estimates for the direct and indirect benefits of CL in Equations (3a) and (3b).

IV. The data source and specifications for the key variables

The data we will be using to estimate the benefits of HAs dementia come from the National Alzheimer's Coordinating Centre (NACC). NACC has constructed a panel data set that has been operational since 2005, called the Unified Data Set (UDS). These data consist of demographic, clinical, diagnostic, and neuropsychological information on participants with normal cognition, mild cognitive impairment, and dementia who visited 32 US Alzheimer's Disease Centres (ADC). In our analysis for this study there were 84,264 visits recorded, for 28,881 individuals, covering up to 12 visits per client, over a 13-year period. This data set is fully explained elsewhere (Morris et al. 2006; Beekly et al. 2007; Weintraub et al. 2009). The UDS was also the data source used for the three prior CBAs of dementia interventions mentioned in the introduction.

The measure of dementia

The pathology of dementia may include plaques and fibres for Alzheimer's disease, and include lesions if vascular dementia is applicable. At this time, no treatments exist that can alter the pathology of the brain. But, since dementia can also be defined as a problem that disrupts a person's daily way of living, a criterion for an effective dementia

[5]Note that, in the context of the fixed effects estimation model that we will be using, variables that do not vary by individual, or by visit, cannot be included in any estimation equation. The fixed variables are controlled for even though their regression coefficients cannot be estimated. Examples of fixed variables for our data set are: years of education, demographic factors other than age, and hereditary factors (such as whether a client's parents had dementia or not).

intervention would be one where a person is enabled to follow a useful and productive lifestyle. So focusing on finding a reduction of symptoms can be a feasible dementia outcome that any intervention can seek to achieve. Therefore, our measure of dementia focuses on cognitive functioning rather than brain pathology.

The instrument that we will be using to measure dementia is the Clinical Dementia Rating (CDR) scale. The CDR is based primarily on a neurological exam and informant reporting, see Morris (1997). A CDR was administered to each NACC participant at each visit by a clinician. There are six domains in the CDR: memory, orientation, judgement and problem solving, community affairs, home and hobbies, and personal care. Each domain is assessed using a 0 to 3 interval (none, mild, moderate and severe) with a questionable response being scored as 0.5. The CDR-SB (the CDR sum of boxes) is the aggregate score across all six domains and this has a range of 0 to 18.

Corrective lenses

NACC clinicians used a functional impairment criterion for assessing vision acuity. The test was whether the client, who usually wears corrective lenses, has an ability to do everyday activities such as reading or watching television. It is the inability to do these tasks that leads to isolation and dementia symptoms in our study.

Mortality

A person is judged to have died if the person is known to be deceased. The person is classed not dead if the person is not deceased, or is unknown to be deceased.

V. The description of all the variables used in the study and the data summary

All the variables to be used in the two estimation equations are listed in Table 1 together with their definitions. The definitions come from NACC's 'Description of NACC Derived Variables to be Used in Data Analysis' (August 2014) and NACC's Uniform Data Set (UDS) 'Coding Guidebook for Initial Visit Packet' (last modified 14 January 2014).

Table 1. Definitions of all the variables.

Variable	Description
D: CDR-SB	Clinical Dementia Rating (CDR) Sum of Boxes (SB). Total CDR score based on Memory, Orientation, Judgement & Problem Solving, Community Affairs, Home & Hobbies, Personal Care, each of the six categories on a scale of 0–3.
Corrective lenses CL	If the subject usually wears corrective lenses, is the subject's vision functionally normal with corrective lenses? 1 = Yes; 0 = No, if any functional impairment exists (reduced ability to do everyday activities such as reading, watching television).
Mortality π	Subject is known to be deceased. 1 = Deceased; 0 = not deceased, or unknown to be deceased.
Age *A*	Subjects age at time of visit.
Hearing aids: HA	If the subject is wearing a hearing aid, is the subject's hearing functionally normally? 1 = Yes; 0 = No, if any functional impairment exists (reduced ability to do everyday activities such as listening to the radio or television, talking with family and friends).
Visit number	The UDS visit number at NACCs. 12 dummy variables for visit 1 to visit 12. This variable provides the order of the UDS visits made for each subject, regardless of the time between visits and whether the visit was in person or on the telephone. For example, visit 1 = 1 indicates the initial visit and visit 2 = 1 indicates the first follow-up completed.
White	NIH race definition. 1 = White; 0 = Non-White.
Female	Subject's sex. Female = 1; Male = 0.
Height	Subject's height in inches.
Birth month	Month the person was born. 1 = Born between October and December; 0 = Not born between October and December.
Smoking years	Total years smoked cigarettes
BMI	Body Mass Index. Derived using variables height (pounds) and weight (inches). The standardized calculation used is: BMI = [(weight (lbs) × 703) ÷ height (in)]^2.
Geriatric Depression Scale (GDS)	Total GDS score. Sum of the 1 s for the 15 ingredients of the GDS scale, short form.
Residence: *R*	Type of residence: *R*1 = Single- or multi-family private residence (apartment, condo, house); *R*2 = Retirement community or independent group living; *R*3 = Assisted living, adult family home, or boarding home; *R*4 = Skilled nursing facility, nursing home, hospital, or hospice.

Table 2 gives the data summary in terms of the number of observations, mean values, standard deviations and minimum and maximum values. We see that, on average, clients scored a 2 on the CDR-SB dementia scale, and 95% of those who wore corrective lenses had vision that was functionally normal. Average age was 75 years. In our sample, 19% had deceased, 57% were females, 83%

Table 2. Descriptive statistics for all the variables.

Variable	Number	Mean	Standard deviation	Minimum	Maximum
CDR-SB	84,287	2.33	3.71	0	18
CL	84,287	0.95	0.23	0	1
Mortality π	84,287	0.19	0.39	0	1
Age *A*	84,287	74.83	9.79	20	110
HA	14,212	0.87	0.34	0	1
Visit 1	84,287	0.31	0.46	0	1
Visit 2	84,287	0.21	0.41	0	1
Visit 3	84,287	0.15	0.36	0	1
Visit 4	84,287	0.11	0.31	0	1
Visit 5	84,287	0.08	0.27	0	1
Visit 6	84,287	0.05	0.23	0	1
Visit 7	84,287	0.04	0.19	0	1
Visit 8	84,287	0.03	0.16	0	1
Visit 9	84,287	0.02	0.13	0	1
Visit 10	84,287	0.01	0.10	0	1
Visit 11	84,287	0.004	0.06	0	1
Visit 12	84,287	0.0003	0.02	0	1
White	84,287	0.83	0.38	0	1
Female	84,287	0.57	0.49	0	1
Height	79,338	65.51	4.00	37	84
Birth month	84,287	0.25	0.43	0	1
BMI	78,353	27.02	5.12	12	84
Smoking years	73,761	10.46	15.27	0	82
GDS	80,429	1.95	2.46	0	15
*R*1	82,008	0.71	0.45	0	1
*R*2	82,008	0.19	0.39	0	1
*R*3	82,008	0.10	0.29	0	1
*R*4	82,008	0.002	0.04	0	1

were white, and 71% lived in a private residence (residence type 1). When clients did wear a hearing aid, and the majority of clients could hear normally without a hearing aid, 87% of them could hear functionally normally.

VI. Estimation results

Estimating the effects of the vision variables on mortality

The estimates for α_1 and α_2 in Equation (4) are in Table 3. We parcel out the results according to the categories of controls that we identified earlier to accompany the vision variables. In column (1) we list the coefficients for the corrective lenses and dementia variables without any controls. Then in columns (2) to (5) we show how the estimates α_1 and α_2 are affected by the inclusion of the various controls. In column (2) we add demographic variables. Column (3) adds nutrition variables to the demographic variables. Column (4) further adds medical variables, and column (5) shows the full results with the vision variables and all of the controls. The vision estimates with all the controls is the most efficient set and we will use these estimate for our CBA. However, as we can see from Table 3, the column (5) estimates do not differ greatly from the without controls estimates in column (1).

All the variables listed (except the birth month) are significant at least the 1% level. In all the regressions, we can reject the null that the panel Logit estimator is no different from the pooled Logit estimator (see footnote b in Table 3). The coefficients attached to the two vision variables α_1 and α_2 that we later will be using to make our benefits estimates, have the expected signs. All the controls have the expected signs, except for the two demographic variables race and gender. However, for our data set, these apparent anomalies can be reconciled, as we now explain.

The positive sign attached to the white race dummy variable at first sight seems to be counter-intuitive, as it is well known that for most age groups, white people live longer than do black individuals. However, Hummer, Rogers, and Eberstein (1998) report that there is a 'racial mortality crossover' at age 87 for women, and 88, for men whereby there is higher mortality among US whites in comparison to US blacks that is real (found in many studies) and not due to just data misreporting. The fact that the NACC data set contains persons with an average age of 75 means that it is plausible that the crossover effect could have occurred in our study. The positive sign attached to whites is therefore possibly consistent with other findings in the literature.

It is also an almost universal experience that women live longer than males (even though this difference may be currently declining in some countries, due to more persistent smoking habits by females). One important reason for this gender mortality rate difference is that males are more likely to die from cardiovascular diseases (Cutler, Deaton, and Lleras-Muney 2006). If a male appears in our data set of older adults, it must mean that he has not yet died from cardiovascular diseases, and is therefore healthier than males in the general population. This could explain the positive sign to the female variable in our mortality results.

Table 3. Marginal effects estimates for random effects models of corrective lenses and dementia on mortality using Logit (*p*-values in parentheses).[a]

Variables	(1)	(2)	(3)	(4)	(5)
Vision variables					
Dementia: α_1	0.0020***	0.0077***	0.0019***	0.0074***	0.0030***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Corrective lenses: α_2	−0.0037***	−0.0077***	−0.0020***	−0.0055***	−0.0038***
	(0.000)	(0.000)	(0.003)	(0.001)	(0.000)
Demographic					
Age *A*:		0.0041***	0.0007***	0.0031***	0.0016***
		(0.000)	(0.000)	(0.000)	(0.000)
White		0.0420***	0.0069***	0.0253***	0.0176***
		(0.000)	(0.000)	(0.000)	(0.000)
Female		−0.0322***	−0.0040***	−0.0183***	−0.0110***
		(0.000)	(0.000)	(0.000)	(0.000)
Nutrition					
Height			0.0002***	0.0005***	0.0003***
			(0.004)	(0.000)	(0.010)
Birth month			−0.0009**	−0.0023**	−0.0015*
			(0.042)	(0.024)	(0.085)
Medical					
BMI				0.0008***	−0.0005***
				(0.000)	(0.000)
Smoker				0.0003***	0.0002***
				(0.000)	(0.000)
GDS				0.0019***	0.0011***
				(0.000)	(0.000)
Residence					
Community					0.0121***
					(0.000)
Assisted Living					0.0233***
					(0.000)
Nursing home					0.0302***
					(0.000)
Number of Obs.	84,264	84,264	79,315	66,042	64,439
Number of Individuals	28,881	28,881	27,153	25,520	25,173
Chi-Square[b]	27,000***	39,000***	35,000***	29,000***	270,000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

[a]Significance levels on coefficients: *10%; **5%; ***1%.
[b]The Chi-square is for a likelihood-ratio test that ρ = 0, which implies that there would be no difference between using a pooled sample rather than a panel for estimation.

Estimating the effects of the vision variables on dementia symptoms

The estimates for β_1 in Equation (7) are in Table 4. As the Hausman test rejects the null that the difference between the fixed effects and the random effects coefficients are not systematic in all the regressions, we report only the fixed effects results. Although the two-way estimates are the most reliable, for reference, Table 4 has both one-way and two-way fixed effects estimates. With the number of individuals i in the thousands, and the number of visits v only 12, we designate the one-way estimates as corresponding to the individual dummies variables, and designate the two-way model as additionally including the number of visit dummies. In this way, we can see the extent to which the estimates for β_1 vary by including each of the visit numbers.

By including whether an individual wears a hearing aid as an independent variable, we greatly reduce the number of observations we can use for our estimation, as most of our sample do not need to wear hearing aids. We therefore present the results with both the smaller and larger samples. All variables (except for visit numbers 11 and 12) are statistically significant at well below the 1% level. We see that the estimates for vision correction are reasonably invariant to the alternative estimation versions and sample sizes, and have the expected negative sign. As we would also expect, the coefficient attached to age (β_2) is positively related to dementia in all the regressions. Understandably, the more visits clients make the more likely they are to have dementia, since this is why there were referred to the AD clinics in the first place. The only other independent variable in the regressions is hearing aids. This has the expected negative sign and its coefficient is of the same order of magnitude as the vision

Table 4. Estimates for one-way and two-way fixed effects models of the vision variables on dementia with smaller and larger samples (*p*-values in parentheses).[a]

	Smaller sample		Larger sample	
Variable	One-way	Two-way	One-way	Two-way
Corrective lens CL β_1	0.1556**	0.1578**	0.1900***	0.1858***
	(0.047)	(0.042)	(0.000)	(0.000)
Age A β_2	0.2625***	0.1360***	0.1437***	0.0348***
	(0.000)	(0.001)	(0.000)	(0.000)
Hearing aids β_3	−0.1970***	−0.1928***		
	(0.001)	(0.001)		
Visit 2		0.4092***		0.5047***
		(0.000)		(0.000)
Visit 3		0.7610***		0.8957***
		(0.000)		(0.000)
Visit 4		0.9619***		1.1208***
		(0.000)		(0.000)
Visit 5		1.0113***		1.2171***
		(0.000)		(0.000)
Visit 6		1.10403***		1.3005***
		(0.000)		(0.000)
Visit 7		1.0118***		1.2290***
		(0.000)		(0.000)
Visit 8		0.9424***		1.2046***
		(0.003)		(0.000)
Visit 9		1.1424***		1.2593***
		(0.001)		(0.000)
Visit 10		1.0471***		1.1971***
		(0.008)		(0.000)
Visit 11		0.9449**		1.1992***
		(0.037)		(0.000)
Visit 12		0.4758		1.1846
		(0.616)		(0.001)
Constant	18.8213***	−9.2109***	16.1173	−0.8579
	(0.000)	(0.003)	(0.000)	(0.000)
Number of Obs.	14,212	14,212	84,287	84,287
Number of Individuals	5,551	5,551	28,881	28,881
R^2 Within	0.1352	0.1546	0.1168	0.1415
F[b]	14.58***	451.17***	14.34***	14.61***
	(0.000)	(0.000)	(0.000)	(0.000)
Chi-Square[c]	3,166.76***	737.22***	3,572.21***	3,492.18***
	(0.000)	(0.000)	(0.000)	(0.000)

[a]Significance levels on coefficients: *10%; **5%; ***1%.
[b]The F-test is for the null that all the β_i are equal to zero.
[c]The Chi-square is the Hausman test for the null that that the difference between the fixed and the random coefficients estimates are not systematic.

correction variable (β_3 was not statistically significantly different from β_1).

VII. The benefit estimates

Since both the direct and indirect benefits in Equations (3a) and (3b) depend on the VSL amount, we explain first how this was obtained.

The estimate of the VSL

Our estimate of the VSL is derived from the literature. Aldy and Viscusi (2008) obtained a VSL of 5.09 USD million in 2000 dollars from revealed preference choices between occupational risk and wages in the US labour market for those aged 62 in the age group 55–62 years of age (the oldest group in their study). This is the value that Brent (2019) used to carry out his CBA of hearing aids. In that CBA, the VSL amount of 5.09 USD million was used to place a price on a QALY, which was the outcome unit in which benefits were expressed for the hearing aids CBA. In this CBA of corrective lenses, we can use the same VSL figure for our benefit measure, since in this study we directly rely on the VSL as the outcome unit.

Hammit and Haninger (2010) point out that there could be a conceptual difference in magnitude between a VSL estimate that relates to a death that comes from an illness that is drawn-out, such as cancer, rather than a death that comes suddenly from an accident at work, which is the context for the Aldy and Viscusi VSL labour-market based figure that we intend to use. A long drawn-out death may give a person the opportunity to plan their estate, something an accidental death would not provide. Death from dementia would seem to fit into this long drawn-out death category.

However, there are results in the literature that validate our use of the Aldy and Viscusi 5.09 USD million estimate. Firstly, Hammit and Haninger did not, in fact, find in their stated preference study that the VSL estimate for cancer was different from non-cancer diseases. Nor did they find a VSL difference for whether a VSL estimate did or did not cover an illness that affected the brain (which is the case with dementia). And secondly, in a recent meta-analysis of the entire VSL literature by Robinson and Hammit (2016), they found that (in the studies that met their criteria for inclusion) the VSL estimates covering illness-related and accident-related deaths were similar. The VSL mid-point VSL estimate for revealed preference, labour-market accidental deaths was 9.5 USD million; while the mid-point VSL estimate for stated preference, illness-related deaths was 7.7 USD million. They concluded that a central VSL estimate around 8 USD million or 9 USD million 'appears reasonable'. Since these valuations are in 2013 prices, they are comparable to our 5.09 USD million estimate that we intend to use that is in 2000 dollars.

The discounted VSL

There is a time difference between when the expenditure on corrective lenses is incurred and when the lifesaving benefits are realized in the future. In our sample, we have a truncated distribution of times of corrective lenses and times of death because we are dealing with an ongoing survey. We do not know when all the clients will die or finally decide to undertake corrective lenses or not. Therefore, the time-lines we are going to use based on our sample are when clients typically die and when corrective lenses typically takes place, judged by the median. Half of the 24,716 clients that did die at some time in our sample (that is, 12,358) did so by the age of 79 years. For the same number of clients to have had corrective lenses, this occurred much earlier, that is, by the age of 65 years. So, there was a 14-year difference between when a client in our sample typically wore correction lens and when they typically died.

We will use a 3% rate for the discounting. This rate was recommended by Gold et al. (1996) and Brent (2014) for use in health care evaluations, and was the rate used by Brent (2018a) to discount the dementia benefits that arise from years of education. The discount factor for 14 years at a discount rate of 3% is 0.642. Multiplying the VSL of 5.09 USD million by this discount factor produces the discounted VSL figure of 3.27 USDmillion.

The direct and indirect benefits

From Equations (3a) and (5), the direct benefits are $\alpha_2\overline{VSL}$. Using the estimate of α_2 from Table 3, equal to (–) 0.0038, and our VSL estimate of 3.27 USD million, the direct benefits are 12,426 USD per person. The indirect benefits based on Equations (3b), (5) and (7) are $\alpha_1\ \beta_1\overline{VSL}$. With α_1 = 0.003 from Table 3, and β_1 = (–) 0.1858 from Table 4, the indirect benefits are 1,823 USD per person.

VIII. The costs and the net-benefits

According to Vitale et al. (2006), eyeglasses were the least expensive of the correction lens options in the year 2000 (a year contemporaneous with our VSL benefit estimate) as refractive surgery was not common at that time. They estimated an individual's costs of corrective lenses using eyeglasses to be 226.48 USD (the eyeglasses cost 180 USD and 46.48 USD was for the eye examination). They assumed that eyeglasses needed to be replaced on average every 4 years. To obtain our estimate of costs for corrective lenses, we use these per-eyeglasses costs and replacement rate, and apply them to the time line and discount rate used to calculate the benefits.

The typical client buys the first set of glasses at age 65. There is a 14-year span until death at 79, over which the client will have bought 4 sets of eyeglasses at a total, undiscounted cost of 906 USD. If the four purchases take place at ages, 65, 69, 73 and 77, the present value of the costs over the 14 years is 765 USD when discounted at the 3% rate.

With direct benefits of 12,426 USD and indirect benefits of 1,823 USD the total benefits for corrective lenses are 14,249 USD. Subtracting the costs, we obtain a net-benefits amount of 13,484 USD, which is a benefit-cost ratio of 18.6. Corrective lenses are clearly socially worthwhile. Importantly, the indirect benefits alone exceed the costs, which comes from corrective lenses decreasing dementia, and dementia reductions lowering the mortality rate. If the dementia benefits were the only source of benefits, the net-benefits would be 1,058 USD with a cost-benefit ratio of 2.4.

IX. Sensitivity analysis

Since the best estimates did produce such positive outcomes, for the sensitivity analysis we will consider only plausible alternatives that would lower the best estimates. The alternatives we will be analysing are those that would reduce the estimates of the regression coefficients (α_1, α_2 and β_1) and the VSL, and thereby affect the direct and indirect benefits.[6]

For ease of comparison, the first row of Table 5 reproduces the best estimates. For rows 2 to 4, we consider the lower bound estimates of the 95%

[6]Any cost differences under consideration would be easy to summarize, as they simply reduce the benefit-cost ratios proportionately. For example, doubling the costs would simply halve the benefit-cost ratio. Note that Vitale et al.'s (2006) amount that we used for costs was already considered to be a conservative estimate.

Table 5. Alternative estimates of the regression coefficients and the VSL leading to lower net-benefit outcomes.

	α_1	α_2	β_1	VSL	B	C	B–C	B/C
1	0.0030	0.0038	0.1858	3,270,000	14,249	765	13,484	18.6
2	0.0030	0.0038	0.1166	3,270,000	13,570	765	12,805	17.7
3	0.0024	0.0038	0.1858	3,270,000	13,884	765	13,119	18.1
4	0.0030	0.0013	0.1858	3,270,000	6,074	765	5,309	7.9
5	0.0024	0.0013	0.1166	3,270,000	5,166	765	4,401	6.8
6	0.0030	0.0038	0.1858	2,700,000	11,765	765	11,000	15.4
7	0.0024	0.0013	0.1166	2,700,000	4,266	765	3,501	5.6

confidence intervals, one at a time, that are related to the three relevant regression coefficients in Tables 3 and 4. In row 5, we consider the simultaneous reduction of all three coefficients. In row 6, we take the lowest VSL estimate that Robinson and Hammit (2016) found in their survey of the VSL literature that was taken from Corso, Hammit, and Graham (2001).[7] The worst-case scenario is shown in row 7. This combines the lowest estimates for the three regression coefficients with the lower bound VSL estimate.

Table 5 shows that none of the plausible alternative estimates considered, which lower total benefits, produce negative net-benefit outcomes. In all cases, the net-benefits are strongly positive, with benefit-cost ratios above 5. We can therefore be reasonably confident that corrective lenses are socially worthwhile. The indirect benefits stemming from dementia alone (not shown in the table) exceeded the costs for all the alternative estimates except for the worst-case scenario (where the benefits and costs would be equal).

X. Summary and conclusions

Corrective lenses lower the probability of dying for older adults directly, and indirectly by lowering the symptoms of dementia as we hypothesized in the introduction. The total benefits of lowering this mortality risk are so large that the net-benefits per person are 13,484 USD, producing a benefit-cost ratio in the double digits. The positive net-benefits are robust to a number of plausible alternative estimates. The benefits are so clearly positive that even if the indirect benefits were considered on their own, the benefit cost-ratio would be greater than two. Given the size of the net-benefits, it is surprising that Medicare Part A and Part B does not usually cover vision tests and corrective lenses, though some Medicare advantage plans do cover these services. Medicare Part B (Medical Insurance) only pays for CLs if a person has had cataract surgery to implant an intraocular lens. This omission by basic Medicare to include CLs is something that needs to be remedied.

Although, at this time, there are no medications that can affect dementia through altering brain pathology, there are available interventions today that can reduce the symptoms of dementia in the future. These interventions generate monetary benefits in a number of different ways that can more than outweigh the monetary costs of these interventions, see Brent (2018a, 2018b, 2019). Both adding years of education, and being eligible for Medicare, reduce the symptoms of dementia and allow many individuals to go into independent living conditions, thereby producing benefits in the form of savings in caregiving expenses. Then it was found that investing in hearing aids increases ones quality of life, which is something that individuals are willing to pay for. Now in this study we see that corrective lenses reduce the chances of dying, and individuals are, in their labour market choices, willing to accept lower remuneration in order to work in less risky occupations.

In the prior CBA of hearing aids, hearing aids were shown to increase the quality of life. The benefits of hearing aids were assumed not to involve changes in the quantity of life. In this study, we now learn that hearing aids also reduce mortality, and in this way add to the quantity of life. Using the VSL valuation method of this study, the added life years would make hearing aids even more beneficial than they already have been found to be. Again, Medicare should not be reluctant to provide services for the elderly that have been shown to be so socially worthwhile.

The dementia interventions evaluated using a CBA methodology (years of education, Medicare eligibility, hearing aids and vision correction) all have in common that they reduce the symptoms

[7] A standard criticism of any VSL estimate based on individual labour market decisions related to compensation for the greater risk of dying is that those who accept the greater occupational risk are those who are risk neutral, which may not be representative of the population as a whole. This criticism is not valid for the $2.7 million alternative VSL that is in Table 5, as this estimate was obtained by contingent valuation (stated preference) and not based on labour market choice (revealed preference). $2.7 million is the $4.2 million VSL figure from Corso, Hammit, and Graham (2001) multiplied by the 0.642 discount factor.

of dementia in the future. They thus complement the interventions that have been discovered to reduce the symptoms of dementia in the present. Cognitive rehabilitation involves occupation therapists reducing dementia symptoms by coming into dementia patients homes and showing them how to improve the tasks that they have opted to tackle. The Tailored Activity Program (TAP), see Gitlin et al. (2009, 2010), enables occupation theorists to address the needs of the caregivers as well as aiming to alter the behaviour of the dementia patients. TAP saves caregiver's time spent. These time-savings can be valued by the opportunity cost of labour to form caregiver benefits in monetary terms. Adding caregiver benefits to the direct and indirect benefits included in this study would make the net-benefits of CLs even larger.

The main methodological contribution of the paper (apart from identifying the indirect benefits of reducing the symptoms of dementia) is to include in a CBA of CLs mortality benefits, in terms of reducing the risk of dying. In the global CBA of CLs by Fricke et al. (2012) for the WHO, they only included productivity losses (foregone GDP) as their measure of benefits. These productivity benefits, estimated to be 202 billion USD, were 10 times larger than the costs of 20 billion USD for setting up a health care system to accommodate CLs for all who need them (covering the costs of educating the additional personnel, and of establishing, maintaining and operating the refractive care facilities). Productivity losses is the human capital (foregone earnings) method for valuing benefits. These losses are mainly incurred by persons other than those experiencing the life-saving benefits that CLs provide, which we have estimated in our CBA. From the perspective of a social evaluation, covering the effects of an intervention on everyone in society, these productivity benefits should be regarded as an positive externality and not the main benefits of CLs. Mortality benefits need to be estimated separately by the WHO, and added to the productivity benefits, to produce a more complete CBA of CLs.[8]

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[8]For a complete CBA of CLs, one also needs to add the costs of purchasing the CLs, as was done in our paper. In the WHO study, they excluded the costs of purchasing the CLs from the costs of running the new facilities, because they assumed that these costs would be recovered from charges to patients. A social evaluation includes all the costs for everyone affected by an intervention, irrespective of whom actually pays for them.

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