Eye Exams for Children: Their Impact and Cost Effectiveness

Prepared by Abt Associates for the Vision Council of America
Acknowledgements

We are grateful for the contributions made by the expert panel that advised us on the study. This panel included Alex Kemper M.D., M.P.H., M.S; William Reynolds O.D.; James Tielsch Ph.D., M.H.S.; and Joel Zaba, M.A., O.D.

The panel provided general guidance on the structure of the model, suggestions about relevant articles to include in our literature review, gave input as to the values of model inputs, and reviewed the Final Report.

We also wish to thank Paulette Schmidt O.D., M.S and Susan Taub M.D., F.A.C.S. for the articles that they furnished to us.

This report was prepared by:

Abt Associates, Inc.
55 Wheeler St
Cambridge MA 02138

The author of the report is Alan J. White, Ph.D.
Executive Summary

Comprehensive eye exams and vision screenings are two methods used to detect amblyopia and other visual disorders in children. Eye exams are performed by an ophthalmologist or optometrist and are used to diagnose vision problems. Vision screenings are conducted by non-medical volunteers, nurses and pediatricians and used to identify people at risk for vision problems.

The goal of the study was to estimate the impact and cost effectiveness of providing comprehensive eye exams to all preschool-age children. We compared the universal provision of eye exams to two interventions: (1) a system in which all preschool-age children receive a vision screening and (2) the eye care that would be provided to children even without the presence of a formal vision screening or eye exam program.

Results

(1) Eye exams would detect, treat and cure significantly more cases of amblyopia in children than a universal vision screening program or the “usual patterns of care” that would exist without a formal vision screening program in place.

It is estimated that nearly 100,000 four-year-olds in America have amblyopia. Even without a formal vision screening system in place, many of these children would have their vision problems identified and treated as part of the usual health care they receive.

However, replacing a system that relies on “usual care” with one that provides universal eye exams would result in 51 percent more children receiving successful treatment for amblyopia by age 10. The following table compares the effectiveness of universal eye exams to “usual care”:

<table>
<thead>
<tr>
<th>Percent of amblyopia cases…</th>
<th>Universal Eye Exams</th>
<th>Usual Care</th>
<th>Percent Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receiving treatment by age 10</td>
<td>98%</td>
<td>77%</td>
<td>27%</td>
</tr>
<tr>
<td>Receiving successful treatment by age 10</td>
<td>68%</td>
<td>45%</td>
<td>51%</td>
</tr>
</tbody>
</table>

Universal eye exams would also outperform a program of universal vision screenings and successfully treat 33,000 (144 percent) more children with amblyopia. The table below compares the effectiveness of universal eye exam and universal vision screening programs:

<table>
<thead>
<tr>
<th>Cases of amblyopia…</th>
<th>Universal Eye Exams</th>
<th>Universal Screenings</th>
<th>Difference</th>
<th>Percent Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detected in initial visit</td>
<td>94,171</td>
<td>64,433</td>
<td>29,738</td>
<td>46%</td>
</tr>
<tr>
<td>Receiving treatment</td>
<td>75,337</td>
<td>30,928</td>
<td>44,409</td>
<td>143%</td>
</tr>
<tr>
<td>Successfully treated/cured</td>
<td>56,503</td>
<td>23,196</td>
<td>33,307</td>
<td>144%</td>
</tr>
</tbody>
</table>
(2) A universal comprehensive eye exam program would be highly cost effective and produce a greater return on investment than many other health care interventions.

Our measure of cost effectiveness is based on a comparison of the costs of these interventions against the improvement in outcomes (quality/length of life) they generate. Cost effectiveness is measured in QALYs (quality-adjusted life-years), a unit that expresses the additional costs required to generate one year of perfect health (1 QALY).

There are no universally accepted standards, but if an intervention costs less than $50,000 per QALY it is generally considered cost effective; if it costs less than $20,000 per QALY, it is generally considered highly cost effective. Assigning a QALY value to different interventions allows policymakers and providers to prioritize and focus on interventions that give the greatest return at the lowest cost.

Replacing a system of “usual care” with universal preschool-age eye exams was highly cost effective at a cost of $12,985 per QALY. Universal eye exams were also highly cost effective when compared to universal vision screenings at cost of $18,390 per QALY. The table at right provides QALY values of other common medical interventions (ophthalmic interventions in bold.)

### Background

Amblyopia affects up to five percent of the population and is the leading cause of unilateral vision loss among those aged 20 to 70. The consequences of untreated amblyopia may include blindness, problems with school performance and effects on quality of life. A number of previous studies have found that early detection of amblyopia provides the best opportunity for effective treatment.

Comprehensive eye exams are considered by all eye care professionals to be the “gold standard” for detecting amblyopia and other vision problems in children. Several studies also suggest that eye exams are more effective than vision screenings in terms of ensuring appropriate treatment for amblyopia. However, they are more costly to perform than vision screenings.

A recent study suggests that vision screening, even when performed by pediatric eye specialists, identifies only about three-fourths of children with amblyopia.
It is almost certain that vision screening tests given by non-eye care professionals are less effective. In addition, several studies suggest that many children who fail a vision screening do not receive the appropriate follow-up evaluation and care.

As a result of the performance differences between exams and screenings, some children who receive comprehensive eye exams are likely to have amblyopia identified and treated earlier than if they had received a vision screening.

**Methodology**

Our goal was to determine if the benefits resulting from exams’ higher rates of detection and treatment offset their higher costs. By understanding the costs and likely benefits, one can better evaluate the level of resources society should devote towards promoting eye exams for all preschool children.

We assessed the cost effectiveness by using cost-utility analysis. This is a method of economic evaluation that analyzes the cost effectiveness of interventions by comparing the benefits of a medical intervention (in this case, eye exams) to the costs of providing that intervention (in this case, both examination and treatment expenses).

Our cost-utility analysis is measured in QALYs (quality-adjusted life-year), a unit that expresses the additional costs required to generate a year of perfect health. A QALY takes into account both quantity and the quality of life generated by intervention being studied and provides a common unit of measurement by which a wide range of medical interventions can be compared.

Because comparisons of cost-effectiveness can be made among interventions, cost-utility analysis means that priorities can be established based on those interventions that are inexpensive (low cost per QALY) and those that are expensive (high cost per QALY). An intervention is generally considered cost effective if it costs less than $50,000 per QALY and generally considered highly cost effective if costs less than $20,000 per QALY.

The economic model we developed to compare these interventions focuses on amblyopia. This is the only vision disorder typically identified during comprehensive exams/vision screenings for which there was sufficient information in the medical literature. Given an initial prevalence of amblyopia in the study population, the model takes into account the following:

1. The relative performance of comprehensive exams and vision screenings;
2. The probability that treatment is successful;
3. The costs of exams, screenings, and treatment;
4. The utility values associated with healthy vision, amblyopia, and amblyopia-caused bilateral impairment;
5. Patterns of treatment under usual eye care.

To estimate model parameters, we conducted an extensive literature review and also consulted with the panel of experts who advised us on the study. While there is an extensive literature on amblyopia and other visual disorders, there are significant gaps that affect our ability to precisely measure
several key model parameters and differences across relevant studies in their estimates of model parameters.

For example, little data has been published on the relative performance of comprehensive exams and vision screenings, the costs and outcomes associated with treating amblyopia, or the impact of untreated amblyopia on quality of life. We developed a set of base values that represent our best estimates, but these are subject to uncertainty given the range of values found in the literature.

Sensitivity analyses were used to examine how results change using different values of model parameters. We found that changes in the values of most model parameters had marginal impact on the basic conclusions of the report. However, results were particularly sensitive to assumptions made about the quality of life associated with untreated amblyopia, prevalence, and the probability of successful treatment.

**Conclusion**

The study’s conclusions are largely driven by the fact that treatment of amblyopia is extremely cost effective. While data are limited, we estimate that treating amblyopia (not including detection) costs about $1,800 per QALY. As a result, spending additional dollars on interventions that detect and treat large numbers of children with amblyopia are also highly cost effective.

That a vision screening costs less to perform than an eye exam is not the only relevant factor in assessing cost effectiveness. What is relevant is a comparison of the costs and the benefits associated with each procedure. Based on our evaluation, the higher costs associated with eye exams are more than offset by the gains that result from the additional children who are successfully treated as a result of receiving an eye exam.

In conclusion, it was beyond the scope of this study to address issues related to the feasibility of requiring comprehensive eye exams for preschool children. However, the study suggests that policymakers should give consideration to programs that would increase the number and proportion of preschool children who receive a comprehensive eye exam from an eye care professional.

These gaps in our knowledge illustrate the clear need for further research on amblyopia and other visual disorders in order to refine estimates of model parameters, allowing for more precise estimates of the costs and benefits of comprehensive exams.
Contents

Acknowledgements................................................................................................................................. i

Executive Summary ................................................................................................................................. ii

1. Introduction ........................................................................................................................................... 1

2. Literature Review and Model Parameters .......................................................................................... 2
   2.1. Prevalence of Amblyopia ............................................................................................................. 2
   2.2. Treatment for Amblyopia ............................................................................................................ 5
   2.3. Performance of Routine Vision Screening and Comprehensive Exams .................................... 6
   2.4. Costs of Vision Screenings, Comprehensive Exams, and Treatment for Amblyopia ............ 9
   2.5. Treatment Patterns Under Usual Eye Care .............................................................................. 11
   2.6. Utility Values Associated With Amblyopia ............................................................................. 12
   2.7. Utility Values Associated with Treatment for Amblyopia ....................................................... 15
   2.8. Discount Rate on Costs and Effects ......................................................................................... 15

3. Methods ................................................................................................................................................ 16
   3.1. Scope of Study ............................................................................................................................ 16
   3.2. Modeling Approach ................................................................................................................... 16
   3.3. Model Structure ....................................................................................................................... 18
   3.4. Model Parameters .................................................................................................................... 19
   3.5. Outcome Measures .................................................................................................................. 23

4. Results .................................................................................................................................................. 24
   4.1. Base-Case Analysis .................................................................................................................. 24
   4.2. Sensitivity Analyses .................................................................................................................. 29

5. Summary and Conclusions .................................................................................................................. 40
   Overview of Study Methodology ....................................................................................................... 40
   Overview of Study Findings .............................................................................................................. 40
   Comparison to Other Medical Interventions ..................................................................................... 41
   Study Limitations .............................................................................................................................. 43
   Discussion .......................................................................................................................................... 44

Technical Appendix: Mathematical Description of Model ................................................................. 45
   Performance Measures: Cost per Quality-Adjusted Life Year ....................................................... 45
   Lifetime Quality-Adjusted Life Years ............................................................................................... 45
   Lifetime Costs Associated With Childhood Eye Care ................................................................. 46
   Utility Values Associated With Each Health State ....................................................................... 46
   Health State Probabilities ............................................................................................................. 46
   Performance of Comprehensive Exams and Vision Screenings ................................................... 47
   Modeling Patterns of Usual eye care ............................................................................................... 49

References ............................................................................................................................................... 52
1. Introduction

Amblyopia is the loss of visual acuity on one or both eyes due to abnormal binocular interaction. Affecting 1 to 5 percent of the population,\textsuperscript{1-11} it is the leading cause of unilateral vision loss among those aged 20 to 70,\textsuperscript{12-13} and is responsible for vision loss in more people under age 45 than all other ocular conditions and trauma combined.\textsuperscript{14} The consequences of untreated amblyopia can include irreversible vision loss, problems with school performance, and effects on quality of life.\textsuperscript{14} A number of previous studies have found that early detection of amblyopia provides the best opportunity for effective treatment.\textsuperscript{16-25} 

Comprehensive eye exams and vision screening assessments are two methods that are used to detect visual disorders in preschool children. Comprehensive eye exams are performed by an eye care professional (ophthalmologist or optometrist) and are diagnostic procedures that include testing of all aspects of vision, including diagnosis and detection of amblyopia. Vision screenings are conducted by pediatricians, school nurses, or volunteers and are more general eye tests that are meant to help identify people who are at risk for vision problems.\textsuperscript{14} According to Schmidt\textsuperscript{14}, vision screening “at best, is a rudimentary observation to detect the presence or absence of general categories of vision problems.”

Comprehensive exams are more costly than vision screenings. Little is known about the relative performance, but several studies suggest that comprehensive exams are more effective than vision screenings in terms of detecting amblyopia\textsuperscript{27-29} and more likely to result in the receipt of appropriate follow-up care.\textsuperscript{5,30-32} As a result, some children who receive comprehensive eye exams are likely to have their vision problems identified and treated earlier than if they had a vision screening. The cost effectiveness of comprehensive exams depends on how the benefits that result from this additional detection and treatment compare to the additional costs associated with comprehensive exams.

Data are limited on the receipt of eye examinations and vision screenings among preschool children. The studies that do exist, however, estimate that only around 22 percent receive some type of vision screening\textsuperscript{19} and only 14 percent receive a comprehensive vision exam.\textsuperscript{26} Kentucky currently requires that children have a comprehensive eye exam furnished by an optometrist or ophthalmologist prior to public school entry.

The purpose of this study is to estimate the cost effectiveness of comprehensive eye exams relative to vision screening and to patterns of usual eye care that occur in the absence of a screening program. Cost effectiveness was assessed using a cost-utility framework in which the quality-adjusted life years (QALYs) associated with comprehensive eye exams were compared to the incremental costs associated these exams, costs that include both the exam costs and the costs of treating children whose conditions are diagnosed as a result of the exam. Cost effectiveness analysis provides a tool that can inform decisions in an explicit, quantitative, and systematic manner.\textsuperscript{35}

In order to evaluate the level of resources that society should devote towards vision exams for preschool children, it is important to develop an understanding of the costs and likely benefits of the exams. The key question that the study attempts to address is whether the benefits to society associated with comprehensive eye exams offset the higher costs of these exams. To assess the cost effectiveness of comprehensive exams, we used a Markov model that permitted variations in the
values of key model parameters, allowing examination of cost effectiveness under a range of alternative parameter values suggested by the literature. Our approach is similar to that used by other studies to assess the cost effectiveness of vision screening programs and treatment for amblyopia.

To estimate model parameters, we conducted an extensive literature review and also consulted with several eye care professionals who advised us on the study. While there is an extensive literature on amblyopia and other visual disorders, there are significant gaps in the literature that affect our ability to measure accurately several key model parameters and differences across relevant studies in their estimates of model parameters. The cost effectiveness analysis is restricted to amblyopia, the only visual disorder identified during preschool eye exams and screenings for which there is sufficient information in the literature for developing model parameters.

2. Literature Review and Model Parameters

The cost effectiveness of comprehensive exams depends on the following parameters:

- Prevalence of amblyopia
- Probability of successful treatment of amblyopia, given age at start of treatment
- Performance (sensitivity and specificity) of comprehensive exams and visions screenings
- Receipt of follow-up care for vision screenings and comprehensive exams
- Costs (of vision screenings, comprehensive exams, and treatment for amblyopia)
- Utility values for amblyopia and amblyopia-caused blindness
- Transition rates from healthy vision to amblyopia, unilateral to bilateral visual impairment, and mortality rates
- Discount rate on future utilities and costs

We conducted an exhaustive literature search to guide selection of the values for these parameters.

2.1. Prevalence of Amblyopia

There are few studies that have measured the prevalence of amblyopia using a large, nationally representative sample, and no studies with the primary aim of estimating the prevalence of amblyopia and refractive errors at 3-4 years of age. Studies differ in their estimated prevalence of amblyopia, depending on the population studies and the definition used (see Table 1). Many of the studies that estimate the prevalence of amblyopia use data collected as part of the assessment of screening tests, but this approach can underestimate the true prevalence because those with false-negative screening results are not included.

The lack of a standard definition of amblyopia in previous studies is a limitation in the literature. According to Snowdon and Stewart-Brown, “a comparison of the yield from screening programs, that is the proportion of children in the screened population, is complicated by the absence of precise definitions of the conditions in the studies… The level of acuity at which amblyopia is considered significant may not be defined, and the type and degree of refractive error included in prevalence estimates of these errors is not always defined.”
The base values in our model are based on the prevalence estimates from the National Center for Health Statistics. Their estimates are more than 30 years old, but are the only data available that provide prevalence estimates for a nationally representative United States sample. The more recent prevalence estimates from the Vision in Preschoolers Study Group are not appropriate to use in our model, as their study population includes a disproportionate share of children who had failed the Healthy Start vision screening, and is thus not a representative sample.
# Table 1

<table>
<thead>
<tr>
<th>Source</th>
<th>Description</th>
<th>Prevalence</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Center for Health Statistics (1983)(^{38})</td>
<td>Estimates are based on standardized eye examination findings from a national probability sample of the civilian non-institutionalized population examined in the first National Health and Nutrition Examination Survey.</td>
<td>The estimated prevalence of amblyopia was 2.5%.</td>
</tr>
<tr>
<td>Preslan MW, Novak A. (1996)(^{5})</td>
<td>This study estimates the prevalence of common visual disorders (amblyopia, strabismus, refractive errors) in a group of inner-city school children. The screening consisted of Snellen E optotypes presented at a 10-foot test distance.</td>
<td>The estimated prevalence of amblyopia was 3.9%. The estimated prevalence of amblyopia was 3.1% and the prevalence of refractive errors was 8.2%</td>
</tr>
<tr>
<td>Vision in Preschoolers Study Group (2004)(^{4})</td>
<td>The study’s patient population included a sample of 2,588 3-5 year old children enrolled in Head Start. This sample likely over-represents children with vision problems.</td>
<td>Prevalence of amblyopia: 4.6% (3.6% “very important to detect and treat early; 1% important to detect early) Presumed unilateral and worse eye VA of ≤20/64: 1.4% Suspected bilateral: 2.2% Suspected unilateral: 1.0% Strabismus-constant: 2.6% Refractive error: 10.6%</td>
</tr>
<tr>
<td>Zaba JN, Johnson RA, Reynolds WT (2003)(^{39})</td>
<td>Eye examinations for 5,316 children entering the Kentucky school system for the first time were reviewed.</td>
<td>3.40% of children were diagnosed with amblyopia, and 2.31% were diagnosed with strabismus</td>
</tr>
<tr>
<td>Attebo et. al (1998)(^{10})</td>
<td>This was a cross-sectional study in which comprehensive exams were performed on an Australian study population (N=3,654)</td>
<td>The prevalence of amblyopia was 3.2%.</td>
</tr>
<tr>
<td>Kvarnstrom G, Jakobsson P, Lennerstrand G (2001)(^{6})</td>
<td>A longitudinal study of Swedish children born in 1982 (N=3,126)</td>
<td>Prevalence of amblyopia at ten years was 3%.</td>
</tr>
<tr>
<td>Thompson JR, Woodruff G, Hiscox FA, et al. (1991)(^{8})</td>
<td>Cohort of 364 children from a single English county who were referred during 1983 for occlusion therapy.</td>
<td>3% (by age of 8)</td>
</tr>
<tr>
<td>Feightner JW (1994)(^{40})</td>
<td>Data from two Ontario communities</td>
<td>The prevalence of combined amblyopia and strabismus is estimated to be 5%.</td>
</tr>
</tbody>
</table>
2.2. Treatment for Amblyopia

Importance of Early Detection and Treatment

The consensus in the literature is that earlier detection and treatment of amblyopia is beneficial. According to the *American Academy of Ophthalmology (2002)*, “Detection of eye abnormalities in the young pediatric age group is particularly important because infants and young children are uniquely susceptible to permanent central visual loss (amblyopia) from opacities of the media (e.g., congenital cataracts), uncorrected refractive errors, strabismus, and other conditions that affect the quality of the visual image. By contrast, these factors do not predispose to irreversible visual loss in the mature visual system of the older child or adult. The visual pathways continue to develop from birth to approximately age 10, during which time amblyopia is amenable to treatment.”

The U.S. Preventive Services Task Force Guide to Clinical Preventive Services states that failure to detect and treat amblyopia at an early age may result in irreversible visual defects and later restrictions in educational and occupational opportunities and also an increased risk of blindness. There is limited data on the effectiveness of treatment for amblyopia—no clinical trials have been conducted; indeed such trials may be unethical. Indirect evidence on the effectiveness of treatment is based on cohort studies of those who have been diagnosed with amblyopia. The most comprehensive analysis of the relationship between treatment success and age is the meta-analysis conducted by Flynn et al. The authors of this study reviewed 23 studies that included a total of almost 700 patients and also analyzed a pooled data set that included almost 600 patients. Based on a logistic regression approach, they found a significant relationship between age and treatment success—relative to age group 0-3, the odds ratio for success of treatment started at age 4-5 was 0.47 and at age group 6-10 it was 0.32. A number of other previous studies and recommendations from Expert panels support the importance for early detection and treatment of amblyopia:

- *Vision in Preschoolers Study Group (2004)*: “Early detection increases the likelihood of effective treatment and allows for actions to decrease the negative impact of the disorders.”
- *Wasserman (1992)*: “Earlier treatment of patients who either have or are at risk for amblyopia is widely accepted as leading to improved outcomes.”
- *Flynn, Schiffmann, and Corona (1998)*: Univariate analyses showed that success of treatment for amblyopia was related to the age at which therapy was initiated.
- *Williams et al. (2002)*: “Data support the hypothesis that early treatment for amblyopia leads to a better outcome than later treatment and may act as a stimulus for research into feasible screening programmes.”
- *Epelbaum et al. (1992)*: This study found that the effectiveness of treatment was highest for children under the age of 3 and that the probability of successful treatment decreased after three years of age. After the age of 12, treatment was ineffective.
- *Monte (1999)*: “When detected early, amblyopia and many other childhood vision abnormalities are treatable, but the potential for correction and normal visual development is inversely related to age.”

In addition, several expert groups, including the US Preventive Services Task Force and the American Academy of Pediatrics (AAP) Committee on Practice and Ambulatory Medicine
recommend that children be screened by age 4, suggesting their belief in the importance of early
detection and treatment. Healthy People 2010 states that early recognition of amblyopia and other
visual disorders “results in more effective treatment that can be sight-saving or even life-saving.” 46
One of the Healthy People 2010 objective is to increase the proportion of preschool children receive a
that, if the risk factors for amblyopia are detected in infancy or early childhood, amblyopia “in
principle, at least, is completely preventable.”

There are some studies that suggest that age is not related to treatment success—According to a
publication from the American Optometric Association, “Effectiveness of Vision Therapy in
Improving Visual Function,” “the question of age and its influence on the efficacy of amblyopia
therapy has been addressed in a number of studies and reviews… It is clear from the evidence that
amblyopia and its oculomotor components can be successfully treated with occlusion and active
vision therapy for a wide range of patients of all ages.” 48 According to Snowdon and Stewart-
Brown27, “the few studies which provide information on what would be expected to happen to the
vision of children with any of the target conditions at 3-4 years of age in the absence of the
intervention do not support the need to treat these children, but there are many important gaps in the
data. Lack of documentation of the natural history of the target conditions means that it is impossible
to estimate the effect of treatment from studies which have no control group.”

While other studies have also found no relationship between the age at which treatment begins and
treatment success, 48-53 the parameters that we use in our model reflect the general consensus in the
literature that early treatment leads to better outcomes. We follow Konig and Barry36 and use the
results of the two Flynn et al. studies4243 as the parameters for the probability of successful treatment
as a function of age, and we also use these parameters in our model. We assume a mean success rate
of 75 percent (for age 3) with a range of 60 – 90 percent. (The mean success rate for treatment started
at age 4-5 was 58 percent and it was 49 percent for age 6-10.)

2.3. Performance of Routine Vision Screening and Comprehensive
Exams

Some of the most important model parameters relate to the performance of routine vision screenings
and comprehensive eye exams in detecting amblyopia and other target conditions relative to
comprehensive eye exams. Of particular importance is the sensitivity of screenings and exams.
Sensitivity is a measure of the percentage of children whose condition will be missed by the screening
method. The lower the sensitivity, the more children with vision problems are missed and not
referred for appropriate follow-up care. Specificity, the percentage of “false referrals” (i.e., referrals
for a condition that does not actually exist), is a less important measure of performance.

Performance of Routine Vision Screening

While concern about the performance of routine vision screenings is the major reason for supporting
comprehensive eye exams, there are significant limitations in the literature related to this topic.
According to Kemper, Margolis, Downs et al., “few high-quality data exist regarding the performance
of preschool vision screening.” 35 The authors of this study conducted an extensive search for articles
on this topic published between 1966 and 1999, and they found only one “high quality” study of
traditional vision screening and three of photoscreening. High quality studies were defined as those in which all or a random sample of those who passed the screening and all those who failed the screening received a formal “gold standard” ophthalmologic exam in which the person conducting the exam was blinded to the results of the screening; the screener must be masked to the ocular status of the study subject; and the criteria used to define abnormal exams must be defined within the article. None of the high quality studies took place in a primary care setting using usual screening procedures, and each used a different ophthalmologic examination standard, making it difficult to compare results across studies. Little is known about the effectiveness of community screening efforts for amblyopia.\textsuperscript{56}

Schmidt\textsuperscript{14} found that “there is no validated, highly effective method for vision screening of preschool children that is comparable to the (Modified Clinical Technique—a combination of tests that is the “gold standard” for vision screening in children). Noting that “under-referrals have been a consistent problem with visual acuity screening procedures, she describes a large-scale vision screening program that reported a prevalence of amblyopia of 0.43 percent, far below the prevalence rate reported for the general population in the studies described above. This study argued that the low prevalence rate found in the screening exam reflected ineffectiveness in the screening methods.

Other studies have also noted the limitations in our knowledge about the performance of vision screenings. According to Wasserman, Croft and Brotherton\textsuperscript{52}, “very little is known about the performance of vision screening among pediatricians, who provide approximately half of all preventive care delivered to preschool children.” In their Summary of a Task Force Report, Hartmann et al. note that the panel “expressed concern about the lack of scientific data addressing the validity of currently available screening methodologies, the effectiveness of the programs that are being used to implement these methodologies, and the adequacy of follow-up and treatment of children identified by screening programs.”\textsuperscript{57} The Task Force recognized “an urgent need for large-scale, generalizable studies aimed at answering basic questions about the reliability and validity of commonly used screening methods.”

Acknowledging the limitations in the literature, we believe that the best study for measuring the performance of vision screenings is the study by the Vision in Preschoolers Study Group.\textsuperscript{1,41} In this study, the performance of 11 preschool vision tests administered by licensed eye care professionals (i.e., optometrists and ophthalmologists) was compared to test the sensitivity of these tests in detecting children with amblyopia, strabismus, significant refractive error, or unexplained reduced visual acuity. The study population was 2,588 3 to 5 year old children enrolled in Head Start. This large sample size allowed fairly precise estimates of the ability of different vision screening procedures to identify children with amblyopia. An important limitation of this study is that licensed eye care professionals gave the screenings. These professionals are presumably better able to detect visual disorders than the pediatricians, school nurses, and volunteers who typically conduct vision screenings, so the study likely overstates the performance of vision screenings in detecting children with amblyopia. Among children with amblyopia, the mean sensitivity across the 12 tests that this

\textsuperscript{1} Funded by the National Eye Institute, the purpose of the Vision in Preschoolers Study is identify whether vision-screening tests can accurately identify preschool-aged children who would benefit from a comprehensive vision examination because of signs of amblyopia, strabismus, significant refractive error, and associated risk factors. It is a is a multi-phased, multi-center, interdisciplinary, clinical study to evaluate the accuracy of screening tests used to identify preschool-aged children in need of further evaluation for vision disorders. (http://www.nei.nih.gov/neitrials/static/study85.htm).
study examined was 74 percent. This may represent an upper-bound estimate of the sensitivity of vision screenings in detecting amblyopia.

Because of its low prevalence, most other studies do not have a large enough sample of children with amblyopia to be able to estimate this parameter with certainty. A 1999 study found that, while 6 percent of children that passed a vision screening conducted by a trained public health nurse were later found to have a vision problem in need of correction, only one case of amblyopia (out of 37 total cases) was missed during a three-year period. An earlier study estimated that 1.3 percent of children who pass vision screenings may actually have “strabismus, amblyopia, or high refractive errors requiring treatment.” Depending on the underlying prevalence of these conditions in the population, this funding suggests that vision screenings may detect only around 75 percent of children with amblyopia. A 1995 Canadian study found that almost 6 percent of children who passed a vision-screening exam were diagnosed, after receiving a comprehensive eye exam, with a vision problem in need of correction. A study of 1,116 children found that the Teller visual acuity test was associated with a high rate of false-positive results.

### Performance of Comprehensive Eye Exams

There are no studies intended to measure the performance of comprehensive eye exams. As these exams are commonly used as the “gold standard” to measure the performance of vision screenings, we assume that comprehensive exams are more accurate than vision screenings and use sensitivity analyses to test the impact of different assumptions about the relative performance of comprehensive exams. The belief that comprehensive eye exams have high sensitivity and specificity is implicit in their use as the “gold standard” in other studies.

### Vision Screenings and Follow-Up Care

A concern about vision screenings is whether children who fail a screening receive the appropriate follow-up care:

- **Donahue (2000)**: The study found that “many children who failed the screening never received a formal eye examination. Significant obstacles exist in obtaining care for those who fail screening.” Only around 60 percent of children who were referred received appropriate follow-up care.

- **Clemens (2002)**: Abnormal vision screening results were noted in 485 (14.2 percent) children, of whom only 38 percent were recommended for follow-up.

- **Wasserman, Croft, and Brotherton (1992)**: “Difficulties are evident in the plans made for follow-up and with the communication of results to parents among those children who fail vision screening… Two months later, 50 percent of parents whose child had failed a vision test were unaware of this fact on questionnaire follow-up. Nine percent were unaware or unsure that the test had been done, and 41 percent thought that the results were normal… Eighty-five percent of children referred to an eye specialist had made or kept an appointment.”

- **Preslan (1996)**: Nearly 2/3 of the children that failed a vision screening did not comply with the recommended treatment despite immediate access to this care.
• Kemper (1999)\textsuperscript{28}. According to LHD records, documentation of follow-up examination after an abnormal screen was low (hearing 27 percent, vision 25 percent). In contrast, most parents reported follow-up (74 percent hearing, 76 percent vision), and many reported that this resulted in treatment (50 percent hearing, 74 percent vision).

Comprehensive Exams and Follow-Up Care

Because eye care professionals provide comprehensive eye exams, all children who fail an exam have at least an initial contact with an ophthalmologist or optometrist. This does not ensure long-term compliance with treatment, but at least ensures that the initial follow-up care is given.

2.4. Costs of Vision Screenings, Comprehensive Exams, and Treatment for Amblyopia

Costs of Vision Screenings

Peterson et al\textsuperscript{62} report that the cost per child screened was $13.57 for a screening program that was implemented in Tennessee between June-August 1997. This was converted to 2004 dollars using the inflation calculator at \url{http://stats.bls.gov/cpi/#data}, suggesting a current cost of around $15.00 per vision screening. This figure is generally consistent with Snowdon and Stewart-Brown\textsuperscript{27} who report that the costs of screening are not great. They report that the costs of a British screening program were between $14.00 and $21.00 (in 2004 U.S. dollars (converted from British pounds using the historic exchange rate information available at \url{www.x-rates.com} and the inflation calculator referenced above)). In our models, we assumed that the costs of vision screenings were between $10 and $25.

Costs of Comprehensive Exams

To measure the costs of comprehensive eye exams, we analyzed Medicaid and Medicare fee schedules for CPT code 92004 (comprehensive eye exam for new patient). Fee schedules were available for seven states for which Medicaid fee schedules were available (California, Florida, Illinois, Kentucky, Massachusetts, Texas, Wisconsin) The average Medicaid payment amount for a comprehensive eye exam in these states was $62.66 (Table 2). The consensus of the experts that advised us on the study was this amount was lower than the typical cost for a comprehensive eye exam, however, so we assumed that the average cost of comprehensive eye exams was $85.00, which is close to the Medicare reimbursement amount for comprehensive eye exams.

This is higher than the $48.00 Ohio average charge for a child eye exam reported in Milliman USA's Health Cost Guidelines\textsuperscript{63}. Our estimates of the costs for vision screenings and exams reflect only the cost of the exam/screening itself and not any cost associated with lost time to the patient, parent, guardian, or transportation costs.
Table 2
Medicare and Medicaid Fee Schedules for Comprehensive Exams for New Patient (CPT Code 92004)

<table>
<thead>
<tr>
<th>Program</th>
<th>Reimbursement Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medicare</td>
<td>$81.65</td>
</tr>
<tr>
<td>California</td>
<td>$70.48</td>
</tr>
<tr>
<td>Florida</td>
<td>$69.70</td>
</tr>
<tr>
<td>Illinois</td>
<td>$46.55</td>
</tr>
<tr>
<td>Kentucky</td>
<td>$63.02</td>
</tr>
<tr>
<td>Massachusetts</td>
<td>$62.44</td>
</tr>
<tr>
<td>Texas</td>
<td>$63.55</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>$43.89</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>$62.66</strong></td>
</tr>
</tbody>
</table>

Sources: Abt Associates analysis of Medicare and Medicaid fee schedules.

Treatment Costs

There is little data on the lifetime costs of treating amblyopia. Konig and Barry\textsuperscript{36} reported that there are "no published data on the cost of amblyopia treatment." Their cost figures were based on expert opinion from a sample of German ophthalmologists and optometrists (Table 3). The treatment cost estimates of Konig and Barry are similar to those of Membreno et al.\textsuperscript{37} who estimated the aggregate costs of amblyopia treatment. They estimated that mean total costs of amblyopia treatment were $1,623. While there is considerable variance in treatment costs depending on the type of amblyopia, this is a weighted average based on the distribution of types of amblyopia and primary etiologies. Their estimate of total costs includes medical treatment, physician charges, anesthesia charges, surgical center fees, and postoperative topical drops. According to the study’s authors, their cost figures represent high end values and may be considered as maximum costs. Following Konig and Barry, treatment costs are assumed to vary based on the age at which treatment begins, but are otherwise the same regardless of whether the patient was referred from a comprehensive exam or a vision screening.
### Table 3:
Amblyopia Treatment Costs By Age At Start of Treatment: Figures From Konig H and Barry J, Pediatrics 2004 (Feb) 113(2): 95-108

<table>
<thead>
<tr>
<th>Age</th>
<th>Average Treatment Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age 3</td>
<td>$1,611.00</td>
</tr>
<tr>
<td>Age 4</td>
<td>$1,536.00</td>
</tr>
<tr>
<td>Age 5</td>
<td>$1,454.00</td>
</tr>
<tr>
<td>Age 6</td>
<td>$1,363.00</td>
</tr>
<tr>
<td>Age 7</td>
<td>$1,260.00</td>
</tr>
<tr>
<td>Age 8</td>
<td>$1,089.00</td>
</tr>
<tr>
<td>Age 9</td>
<td>$913.00</td>
</tr>
<tr>
<td>Age 10</td>
<td>$665.00</td>
</tr>
</tbody>
</table>

### 2.5. Treatment Patterns Under Usual Eye Care

Even if there is no exam or screening program, many children with amblyopia would be diagnosed and treated as they visit an optometrist or ophthalmologist, perhaps after being referred by a pediatrician or brought in by a concerned parent. But this treatment will often begin later than care that results from an exam or vision screening that is required prior to beginning school, and, as a result, the probability of successful treatment may be lower.

Konig and Barry\(^{36}\) report that there is no data available that reports the age-specific probability that a child with amblyopia will receive treatment under usual eye care. They estimated this probability based on a representative survey of ophthalmologic patients in Germany. Since patterns of usual eye care in Germany may be quite different from those in the U.S., it was not appropriate for us to use their parameter estimates for our model. Instead, our estimates of care under patterns of usual eye care are based on the following:

- According to Ciner et al., “there are many preschool children who are not screened for vision problems until they enter the educational system at age 5 or 6 years.”\(^{26}\)
- Ehrlich MI, Reinecke RD, Simons K estimate that “at most, 21 percent of preschool children receive any form of vision screening.”\(^{56}\) Their estimate was based on an in-depth analysis of existing preschool vision screening programs at the federal, state and private organization levels.
- Based on a study of private pediatric practices in the U.S., Wasserman estimated that only 38 percent of 3-year old children are screened for vision problems.\(^{32}\)
- One study found that only 14 percent of children in the United States have received a comprehensive eye examination by age six.\(^{64}\)
- Another study found that many pediatricians do not follow guidelines regarding vision screening and referral, particularly for younger children.\(^{65}\) This study found that two thirds
of pediatricians do not begin visual acuity testing at age 3 years and about 20 percent do not test until age 5 years.

- A study by the Vision Service Plan reported that 52 percent of parents had taken their child age 12 or under to an ophthalmologist or optometrist. Fifty percent of parents who had taken their child to an eye care specialist indicated that they did so because someone noticed a vision problem. Almost 60 percent of those who had not taken their child for an eye exam said that this was because there were no vision problems evident in their child. This study was based on a telephone survey of 400 parents and had a margin of error of +/- 4.9 percent (at a 95 percent confidence interval).

The Vision Service Plan study suggests that children with amblyopia are more likely to receive an eye exam under usual eye care than children without amblyopia, since it is more likely that someone will notice a vision problem in these children. While there is no guidance in the literature on exactly how much more likely children with amblyopia are to receive a comprehensive eye exam under usual eye care, in our base case, we assumed that they were 2.5 times as likely as other children to receive an eye exam under usual eye care. This implied that 86 percent of children with amblyopia would receive a comprehensive eye exam by the age of 12. We also used the Vision Service Plan figures to guide our estimate of the age-specific probabilities of eye exams under usual eye care, setting model parameters so that 52 percent of non-amblyopic children received an exam by age 12.

2.6. Utility Values Associated With Amblyopia

The cost effectiveness of comprehensive eye exams was assessed using cost-utility analysis, in which the benefits associated with comprehensive exams, which result from earlier detection and treatment, are compared against the costs associated with the exams. The goal of the analysis was to evaluate whether the improvements in health that might result from comprehensive exams justify the expenditures relative to other choices. Benefits were measured in terms of the additional quality-utility values that result from comprehensive exams.

Overview of Quality Adjusted Life Years

Much of the material in this section is from “What is a QALY?” and “Implementing QALYs”, which both provide a general overview of how to use QALYs for cost effectiveness analysis.

A QALY takes account both quantity and quality of life generated by healthcare interventions. It is a quality-of-life measure that estimate individuals’ preferences for given states of health and are generally measured on a scale ranging from 0 to 1, where 0 is defined as being equivalent to death and 1 as equivalent to optimal health. It is the arithmetic product of life expectancy and a measure of the quality of remaining life years. The Panel on Cost Effectiveness in Health and Medicine recommends using QALYs to measure the outcomes of medical interventions.

QALYs are designed to aggregate in a single summary measure the total health improvement for a group of individuals, including both the impact on quantity and quality of life. They provide a common unit of measurement for comparing the benefits that arise from various interventions in terms of health-related quality of life. When combined with information on the costs of the interventions, we are able to calculate the cost per quality adjusted life year, a measure that is known as the cost-utility ratio. While the QALY approach is not without limitations, it allows priorities to be
compared using a common measure (cost per QALY) and can be useful in informing decisions about how best to allocate healthcare resources. To calculate a QALY, the amount of time spent in a health state is weighted by the utility score given to that health state. Utility values are used as the quality-adjustment weights in cost-utility analysis.

The most useful type of cost per QALY measure is the incremental costs per QALY. This is a measure of the marginal benefits and the marginal costs associated with an intervention compared with another intervention. It allows one to assess the additional costs and benefits expected when choosing one intervention (i.e., comprehensive eye exams) over another (i.e., vision screening or usual eye care). This is the relevant measure for assessing

In the U.S., while there is controversy regarding the threshold to use, interventions that have a cost effectiveness of $50,000 per QALY or less are typically considered to be cost effective.68,71-72

Utility Values For Amblyopia and Amblyopia-caused blindness

In our model, there are four health states:

- Healthy (no amblyopia)
- Amblyopia (or other unilateral visual impairment)
- Amblyopia-caused blindness (bilateral impairment)
- Deceased

The healthy state has a utility value of one and death has a utility value of zero. For those with childhood amblyopia, lifetime utility is higher if the amblyopia is successfully treated, and the likelihood of successful treatment increases the earlier treatment begins. Successful treatment of amblyopia also reduces the likelihood of blindness later in life.

We use the same utility values for amblyopia and amblyopia-caused blindness as Konig and Barry.36

Amblyopia

The importance of early detection and treatment for amblyopia, recommended in many other studies, suggests that untreated amblyopia has an important impact on quality of life. According to a fact sheet developed by the American Academy of Pediatrics Project Universal Preschool Vision Screening (PUPVS), “children with … impaired vision may have greater difficulty learning, have trouble participating in organized sports and recreational activities, have limited employment options, may have increased morbidity or mortality due to accidents, and have difficulty with psychosocial development.”73

There are several studies that have addressed various dimensions of this impact. Although these studies do not attempt to estimate the utility value associated with amblyopia, they are useful for understanding how untreated amblyopia impacts quality of life.

- **Wang, Mitchell, and Smith (2000)**: The study found a relationship between visual impairment and self-reported health status. Among persons without visual impairment (defined from best-corrected VA in the better eye), 24.5 percent rated their health as either poor or fair, compared with 35.5 percent and 48.8 percent of persons with mild or moderate-to-severe visual impairment, respectively.
• **Broderick (1998)**\(^{75}\): The article states that children with amblyopia and strabismus experience psychologic difficulties, particularly in opposite-sex friendships during adolescence. Some professions require good binocular vision and therefore exclude persons with strabismus or amblyopia.

• **Hymers, Baker, and Galang (2001)** \(^{76}\): Their study identified 30 occupations into which visual requirements would restrict amblyopic patients from entering the field.

• **National Academy of Sciences (2001)** \(^{77}\): Data from the National Health Interview Survey suggests that visual impairment is associated with lower income—pooled data from 1983-1997 indicates that mean income was about $3,600 per year less for those with an “other visual impairment” (excluding blindness but including disorders of the lacrimal system, disorders of binocular eye movements, and diseases of the retina (but not including cataracts, or glaucoma or blindness). While far from definitive, this suggests that amblyopia may be associated with lower income.

The major exception to the conclusion of these studies is the review published by Snowdon and Brown.\(^{26}\) The authors found that the quality of the literature on visual defects and disability is insufficient to understand what might happen to children whose amblyopia goes untreated. In another study\(^{77}\) published by these authors, they note that trials of treatment for amblyopia do not include a “no treatment” control group, and, as a result, little is known about the natural history of amblyopia, except in an indirect way and for short periods.

According to Konig and Barry\(^{36}\), “the utility associated with unilateral visual impairment caused by amblyopia has not been investigated specifically thus far.” In their model, their utility values for amblyopia are based on a study of patients with unilateral impairment (defined as VA <= 0.5 in the worse eye and VA >= 0.8 in the better eye).\(^{79}\) This study found that visual loss was associated with a “substantial and measurable diminution in quality of life.” Unilateral impairment was associated with a mean reduction of utility of 0.08 using the time trade-off method. Konig and Barry note that individuals with only one good eye due to amblyopia since childhood may develop compensatory visual mechanisms. As a result, the 0.08 reduction in mean utility associated with amblyopia is likely a maximum value. They assumed for the base analysis a utility of 0.96 for amblyopia and varied this utility value from 0.92 to 1.0 in their sensitivity analyses, the same range that we use in this study.

**Bilateral visual impairment**

Untreated amblyopia also increases the risk of blindness as an adult. Following Konig and Barry, we data from the Australian Blue Mountain Eye Study\(^{80-81}\) to estimate the prevalence of amblyopia-caused blindness, which they assumed to be equal to half of the prevalence of unilateral visual impairment in persons without amblyopia with an adjustment to reflect the likelihood that visual acuity in the amblyopic eye may improve when the other eye becomes visually impaired.

• **Tomilla and Tarkannen (1981)**\(^{82}\): In Finland during the 20-year period 1958-78 35 patients with amblyopia lost the vision of the healthy eye. In more than 50 percent the cause was traumatic. The incidence of the loss of the healthy eye was 1.75 +/- 0.30 per thousand. During the same period in Finland the overall blindness rate of children was 0.11 per thousand and of
adults aged 15-64 years 0.66 per thousand. For the amblyopic patient the risk of becoming blind is markedly higher than for the general population.

- Van Leeuwen, Eijkemans, Vingerling, et al. (2003)\textsuperscript{83}: In total, 93 (1.8 percent) subjects developed bilateral visual impairment, including 11 (6.0 percent) subjects with amblyopia. Among amblyopic subjects, the prevalence of bilateral visual impairment increased from 0.1 percent for those aged 55 years, to 40.0 percent for those over 85 years. The estimated lifetime risk of bilateral visual impairment was 18 percent for amblyopic subjects, and 10 percent for non-amblyopic subjects. For newly affected cases, the expected number of years spent with bilateral visual impairment was 7.2 years for amblyopic subjects, compared with 6.7 years for the non-amblyopic population.

Konig and Barry\textsuperscript{36} used a model developed by Sharma and Brown\textsuperscript{84} to estimate that bilateral visual impairment reduces utility by 22 percent (i.e., to 0.78), with a range of 15 to 29 percent. They measured utility using standard reference gamble utilities\textsuperscript{85} and the time trade-off method\textsuperscript{86} using a survey of 323 patients with best-corrected vision of 20/40 or worse in at least one eye. A formula for converting the visual acuity of the better eye to a mean utility value was derived via regression analysis. The Harvard University Catalog of Preference Scores\textsuperscript{87} report a 0.69 utility value for blindness. In our model, we estimate a range of utility values for amblyopia caused bilateral visual impairment, from 0.69 to 0.85 (the upper bound suggested by Sharma and Brown).

2.7. Utility Values Associated with Treatment for Amblyopia

Snowdon and Stewart-Brown\textsuperscript{88} conducted a qualitative study of children with amblyopia and their parents. The study found that many patients found that the treatment (wearing glasses and intermittent patching of the good eye) had had an important and negative impact on their quality of life—children did not like wearing glasses or patches and some parents felt distressed at enforcing these on their children. While Snowdon and Stewart-Brown made no attempt to estimate the utility value associated with the actual treatment for amblyopia, in our model we allowed for the possibility that treatment for amblyopia reduced the quality of life during the treatment period to as low as 0.96, and, in the base case, we assumed that amblyopia reduced the quality of life during the treatment period to 0.98.

2.8. Discount Rate on Costs and Effects

The discount rate on costs and effects is a measure of how costs and benefits that occur in the future should be weighted relative to costs and effects in the present period. Following the recommendations of the Panel on Cost-Effectiveness in Health and Medicine\textsuperscript{89}, we used a discount rate of 3 percent for costs and health outcomes in the base case, although we allowed the discount rate to be as low as 1 percent and as high as 5 percent.
3. Methods

3.1. Scope of Study

The model focuses on amblyopia, the only vision disorder typically identified during comprehensive exams/vision screenings for which there was sufficient information for determining model parameter estimates. In our base case model, we make no attempt to estimate the benefits associated with the detection and treatment of strabismus or other ocular diseases that may be detected as part of a comprehensive exam. Due to limitations in the literature, we also make no attempt to analyze the performance of comprehensive exams and vision screenings with respect to prescription of eyewear. A recent study found that 19 percent of children who failed a vision screening but did not have amblyogenic factors identified in a subsequent exam by an eye care professional were prescribed eyeglasses. The major limitation of this study is that it uses a non-representative study population for determining the specificity (i.e., false positive rate) of comprehensive eye exams. It is likely that the study's sample of individuals who failed a vision screening but had no amblyogenic factors is different in important ways from the overall sample of individuals without any visual disorder (including those who passed a vision screening). In addition, we have concerns about the extent to which incomplete or inaccurate data (i.e., the failure to enter all relevant information in the database) impact the study’s conclusions. This is the only study we identified that addressed the performance of comprehensive exams for eyewear prescription, and we do not have data for all of the parameters that would be necessary to include this parameter in our cost effectiveness analyses.

If comprehensive eye exams lead to inappropriate prescription of eyewear, the net impact, in terms of the cost effectiveness analysis, would be to increase the costs of comprehensive eye exams (i.e., to account for the costs associated with the unnecessary eyeglasses that result from comprehensive eye exams). In our sensitivity analyses, we considered a scenario in which there was inappropriate eyeglass prescriptions at the rate suggested by Donahue.

Further research on the performance of comprehensive exams in the prescription of eyeglasses to preschool children is required before a sufficiently reliable estimate of the costs associated with inappropriate prescription of eyeglasses would be available to incorporate into the base case model.

3.2. Modeling Approach

The cost-effectiveness of comprehensive eye exams was measured based on the cost per QALY of comprehensive exams relative to vision screenings and to patterns of usual eye care in the absence of a preschool vision screening or comprehensive exam program. Based on parameter values for the factors described in the preceding section, we used a Markov decision model framework to describe the detection and treatment of amblyopia under alternative patterns of care. A Markov model is a

---

2 Specifically, it is not possible to distinguish a true false positive eyeglass prescription from a prescription that is appropriate but that is not documented correctly in the database that was established by the Tennessee Lion’s Outreach Program.

3 For example, we do not have data on the sensitivity or specificity of vision screenings for detection of these factors, nor is there any studies that provide estimates of the utility associated with not receiving eyeglasses when they are needed or receiving eyeglasses when they are unneeded.
A mathematical model that is used to analyze transitions between health states. This type of model has been used in many other studies to assess the cost effectiveness of different interventions for the detection or treatment of given diseases. Parameters for the model were based on an extensive review of the relevant literature that is described above.

The cost effectiveness of comprehensive exams depends on the incremental benefits and costs of comprehensive exams (relative to vision screening or usual eye care).

- The marginal benefits of comprehensive exams are the improvements in quality of life that result from additional cases of amblyopia that are diagnosed and treated as a result of comprehensive exams.

- The marginal costs associated with comprehensive exams include both exam and treatment costs.

The model tracks individuals from age 3 (the earliest age at which children could receive a preschool exam) through their lifetime. Following Konig and Barry, we assume that amblyopia can be treated up through age 10, although the probability of successful treatment declines with age. In the initial period, the study population is assigned to one of two health states—either they have amblyopia or they do not have it. In subsequent periods, individuals with amblyopia may move to the non-amblyopia state if their amblyopia is successfully treated. Based on the model parameters discussed below, the probability of successful treatment varies based on whether the individual had a comprehensive exam, vision screening, or no exam. In subsequent periods, individuals are in one of these states:

- Healthy vision. This includes individuals who did not have amblyopia at the beginning of the study period and those whose amblyopia was successfully treated.

- Amblyopia or other unilateral visual impairment. This includes both those with amblyopia for whom the condition was undetected or not successfully treated. It also includes those without childhood amblyopia who develop unilateral visual impairment later in life.

- Bilateral visual impairment related to amblyopia. This cohort is defined to include those who suffer bilateral visual impairment due to untreated amblyopia (i.e., they suffer unilateral visual impairment in their non-amblyopic eye). Following Konig and Barry, since our model focuses only on amblyopia, we considered only bilateral visual impairment that occurred as a result of untreated amblyopia.

- Deceased. While not related to amblyopia, individuals have a probability of dying each year, based on mortality statistics from the National Vital Statistics Report from the National Center for Health Statistics.

Each of these states has an associated utility value, ranging from zero (for deceased) to one (for healthy). QALYs are calculated by weighting the number of years in each of the potential states by the discounted utility value associated with that state. The primary outcome measure used to evaluate cost effectiveness is the cost per QALY of comprehensive exams relative to a preschool vision screening program and to patterns of usual eye care that occur in the absence of a screening program.
Cost per QALY = \((\text{Cost}_{\text{Exams}} - \text{Cost}_{\text{Screening or usual eye care}})/(\text{Utility}_{\text{Exams}} - \text{Utility}_{\text{Screening or usual eye care}})\)

This is a measure of the incremental (or marginal) costs and benefits of comprehensive exams, relative to either vision screenings or usual eye care. It is this measure of marginal benefits and costs that is relevant when assessing the cost effectiveness of comprehensive exams.

For individuals with healthy vision, quality-adjusted life years are the same regardless of the eye care that they received as a child. For those with amblyopia, however, lifetime utility is higher if the amblyopia is successfully treated since the utility value associated with healthy vision is higher than the utility associated with amblyopia. In addition, those whose amblyopia is successfully treated have no risk of bilateral visual impairment related to untreated amblyopia.

### 3.3. Model Structure

The model takes into account the following parameters:

- **Prevalence and incidence** The prevalence of amblyopia in the screening population and the incidence of other unilateral vision loss and amblyopia-related bilateral visual impairment.

- **Performance of comprehensive exams.** The performance of comprehensive exams includes the percentage of children with amblyopia whose condition is detected by exams (i.e., the sensitivity of comprehensive exams); the percentage of false-positive exam results (i.e., specificity); the percentage of those diagnosed with amblyopia who are referred to an eye care professional and who make this initial follow-up visit (i.e., the referral rate); and the percentage of those detected with amblyopia who receive the recommended follow-up care (i.e., compliance or adherence).

- **Performance of vision screenings** There are analogous measures of performance for vision screenings (sensitivity, specificity, referral rate, cooperation/adherence).

- **Treatment outcomes** This is probability of successful treatment for those who receive the recommended follow-up care.

- **Patterns of usual eye care** This is defined as visits to optometrists and ophthalmologists in the absence of required comprehensive exams, including treatment for amblyopia that are detected as part of these exams.

- **Utility values** This is a measure of the quality of life for those with unilateral or bilateral visual impairment relative to the quality of life with healthy vision; this also includes any impact on quality of life associated with the actual treatment for amblyopia.

- **Costs.** Costs included in the model include the costs of comprehensive exams (including those received as part of usual eye care), vision screenings, and costs for the treatment of amblyopia for those who are diagnosed with amblyopia and receive follow-up care as a result.
• **Discount rate** This is the rate at which future benefits (in terms of QALYs) and costs are discounted relative to the present.

More detail on the mathematical structure of the model can be found in the Technical Appendix.

### 3.4. Model Parameters

#### Base-Case Model Parameters

Based on the literature review that is described in Section 2 above, we developed a set of base parameters for all of the factors included in the model. This is consistent with the recommendation of the Panel on Cost Effectiveness in Health and Medicine that a reference case analysis be done to enhance comparability across studies. The base values for these parameters are our best “point estimate” of the parameter based on information from other studies or our own analyses. The justification for selection of these base case values is given in Section 2.

#### Sensitivity Analyses

Reflecting the uncertainty over many of the key model inputs that result from differences in the findings of previous studies, we developed a range of parameter values for sensitivity analyses. We used two types of sensitivity analyses:

- **Univariate sensitivity analyses:** We changed the value of individual model parameters based on the ranges listed in Table 4. This type of analysis is useful for analyzing the effect of uncertainty in individual parameters.

- **Monte Carlo simulations:** Monte Carlo simulation is a method that allows uncertainty in model parameters to be used to generate a confidence interval for the model’s results. We conducted Monte Carlo analyses in which every parameter was allowed to vary independently and simultaneously over the range of parameter values described in Table 4, and the model results were estimated based on the simulated values. Reflecting the considerable range of estimates that exists in the literature, a uniform distribution was used for all parameters. We generated 10,000 simulations to approximate confidence intervals for the cost per QALY for comprehensive exams relative to vision screening. The 95 percent confidence interval of estimated cost effectiveness can be estimated by looking at the 2.5th and 97.5th percentile values (i.e., in 95 percent of the simulations, the estimated cost effectiveness is between these two percentile values).

The ranges used for sensitivity analyses represent our judgment, based on review of the literature and discussions with the experts who advised us on the study. The sensitivity analyses allowed documentation of how results varied based on the parameters used and identified the model inputs affect our findings in important ways. The base values, range used for sensitivity analyses, and description of the sources used for the parameter are described in Table 4.

---

4 The study advisors included Alex Kemper M.D., M.P.H., M.S; William Reynolds O.D.; James Tielsch Ph.D., M.H.S.; and Joel Zaba, M.A., O.D. These advisors were consulted several times during the project. They provided feedback on the general structure of the model, suggested literature references to include in our review of relevant studies, provided input on the values of model parameters, and reviewed the final report.
### Table 4: Parameter Values for Cost Effectiveness Model

<table>
<thead>
<tr>
<th>Model parameter</th>
<th>Base Case Value</th>
<th>Range</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prevalence of amblyopia</td>
<td>2.5%</td>
<td>1 - 4%</td>
<td>2.5% is the prevalence estimated by the National Center for Health Statistics. This study is dated (it’s from 1971-2), but is the only study that uses a nationally representative U.S. sample as its study population. 1% to 5% is the range of amblyopia prevalence estimates cited in the literature, but studies that find a prevalence of 5% typically have a non-representative study population.</td>
</tr>
<tr>
<td>Performance of comprehensive exams</td>
<td></td>
<td></td>
<td>No known reference source exists, but these type of exams are used as the “gold standard” for assessing the sensitivity and specificity of vision screenings.</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>95%</td>
<td>90-100%</td>
<td>No known reference source exists.</td>
</tr>
<tr>
<td>Specificity</td>
<td>98%</td>
<td>96-100%</td>
<td>No known reference source exists.</td>
</tr>
<tr>
<td>Referral to an eye care professional</td>
<td>100%</td>
<td></td>
<td>(By definition, since the exam is performed by an eye care professional)</td>
</tr>
<tr>
<td>Cooperation/receipt of follow-up care</td>
<td>80%</td>
<td>70-90%</td>
<td>No known reference source exists.</td>
</tr>
<tr>
<td>Performance of vision screening</td>
<td></td>
<td></td>
<td>74% is the average sensitivity in detecting amblyopia of the screening tests reviewed in the Vision in Preschoolers Study Group study, this overstates performance, since the tests were conducted by licensed eye care professionals, not the group that typically administers vision screenings, so we adjusted downwards to 65 percent.</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>65%</td>
<td>50%-80%</td>
<td>Sensitivity figures above assumed specificity of 0.90.</td>
</tr>
<tr>
<td>Specificity</td>
<td>90%</td>
<td></td>
<td>There’s a range of estimates in the literature, from around 45-75%</td>
</tr>
<tr>
<td>Referral to an eye care professional</td>
<td>60%</td>
<td>45-75%</td>
<td>No reason for expecting differences in cooperation/follow-up care once initial contact with eye care professional occurs.</td>
</tr>
<tr>
<td>Cooperation/receipt of follow-up care</td>
<td>90%</td>
<td></td>
<td>No reason for expecting differences in cooperation/follow-up care once initial contact with eye care professional occurs.</td>
</tr>
<tr>
<td><strong>Effectiveness of Treatment</strong></td>
<td><strong>75%</strong></td>
<td><strong>60-90%</strong></td>
<td></td>
</tr>
<tr>
<td>--------------------------------</td>
<td>---------</td>
<td>------------</td>
<td></td>
</tr>
</tbody>
</table>
| Effectiveness of treatment started early  
(at time of pre-school exam/vision screening) | This is the success rate of treatment started early used in Konig and Barry[^36]. The studies that they cite report success rates from 50 to 100 percent, the most comprehensive of which is a meta-analysis conducted by Flynn et. al[^43], who conducted a meta-analysis based on 23 studies with 689 patients. 60-90% is the range used by Konig and Barry. |
| Effectiveness of treatment started late: Age 6-10 | 48.74% | 18.7-53.6% |
| Figures are from Konig and Barry[^36] and are based on Flynn et. al[^43]. Previous studies have shown a significant relationship between aged on treatment success. |

<table>
<thead>
<tr>
<th><strong>Patterns of Usual eye care</strong> (Probability of visit to optometrist or ophthalmologist for a comprehensive eye exam per year)</th>
<th><strong>10%</strong></th>
<th><strong>5% - 15%</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Age 4-10</td>
<td>Based on available data on the proportion of children who receive an eye exam each year</td>
<td></td>
</tr>
<tr>
<td>Relative likelihood of treatment under usual eye care for those with amblyopia</td>
<td>2.5</td>
<td>1-4</td>
</tr>
<tr>
<td>There is no known literature to guide selection of these values, but anecdotal evidence suggests that children with amblyopia are probably more likely to visit an eye care professional as part of usual eye care.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Utility values</strong></th>
<th><strong>1.00</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy vision</td>
<td></td>
</tr>
<tr>
<td>Amblyopia</td>
<td>0.96</td>
</tr>
<tr>
<td>Brown et. al[^79] found that unilateral impairment reduced mean utility by 0.08, although those with amblyopia may be able to compensate for this. Konig and Barry[^36] used the range of 0.92 to 1.00 (no disutility).</td>
<td></td>
</tr>
<tr>
<td>Bilateral visual impairment</td>
<td>0.78</td>
</tr>
<tr>
<td>This is the utility of bilateral-visual impairment parameter estimate used by Konig and Barry[^36] and it is based on Sharma et. al[^84] who used the time trade-off method to assess utility.</td>
<td></td>
</tr>
<tr>
<td>Utility associated with period of treatment</td>
<td>0.98</td>
</tr>
<tr>
<td>While there are no studies that we know of that have attempted to estimate the utility value associated with amblyopia treatment, several studies have noted that patients often do not like wearing the patch that treatment often requires. So we allow for the possibility that treatment results in reduced utility during the treatment period.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Costs of Comprehensive Exams and Vision Screening</strong></th>
<th><strong>$85</strong></th>
<th><strong>$65-$105</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Comprehensive Eye Exam</td>
<td>Source: Based on the Medicaid fee schedules for CPT code 92004 (comprehensive eye exam for new patient) in seven states for which Medicaid fee schedules were available (California, Florida, Illinois, Kentucky, Massachusetts, Texas, Wisconsin)—see Table 2.</td>
<td></td>
</tr>
<tr>
<td>Vision Screening</td>
<td>$20</td>
<td>$10-$30</td>
</tr>
<tr>
<td>Source: Peterson et. al[^62], with inflation adjustment based on Consumer Price Index. They</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Report cost per child screened of $13.57 between June-August 1997. This was converted to 2004 dollars using the inflation calculator at http://stats.bls.gov/cpi/#data

<table>
<thead>
<tr>
<th>Treatment Costs, By Age At Which Treatment Started</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Age 3</td>
<td>$1,611</td>
</tr>
<tr>
<td>Age 4</td>
<td>$1,536</td>
</tr>
<tr>
<td>Age 5</td>
<td>$1,454</td>
</tr>
<tr>
<td>Age 6</td>
<td>$1,363</td>
</tr>
<tr>
<td>Age 7</td>
<td>$1,260</td>
</tr>
<tr>
<td>Age 8</td>
<td>$1,089</td>
</tr>
<tr>
<td>Age 9</td>
<td>$913</td>
</tr>
<tr>
<td>Age 10</td>
<td>$665</td>
</tr>
</tbody>
</table>

Figures are from Konig and Barry365, who report that there are "no published data on the cost of amblyopia treatment." The figures are based on expert opinion from a sample of German ophthalmologists and optometrists.

<table>
<thead>
<tr>
<th>Transition Probabilities: Mortality</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Age-specific mortality rate</td>
<td></td>
</tr>
<tr>
<td>Mortality rate assumed not to be related to amblyopia. Mortality rate figures are from the National Vital Statistics Report from the National Center for Health Statistics.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transition Probabilities: Unilateral to Bilateral Visual Impairment</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>49-51</td>
<td>0.0027497</td>
</tr>
<tr>
<td>52-59</td>
<td>0.0004054</td>
</tr>
<tr>
<td>60-69</td>
<td>0.0038352</td>
</tr>
<tr>
<td>70-79</td>
<td>0.0074775</td>
</tr>
<tr>
<td>80-89</td>
<td>0.0057712</td>
</tr>
</tbody>
</table>

According to Konig and Barry36, there is "no data on age and gender-specific incidence of unilateral visual impairment" available in the literature. They used data on the prevalence of unilateral visual impairment by age group, gender, and severity from the Blue Mountain Eye Study.10

<table>
<thead>
<tr>
<th>Discount Rates</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Effects</td>
<td>0.03</td>
</tr>
<tr>
<td>Costs</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Based on recommendations of the Panel on Cost-Effectiveness in Health and Medicine90
3.5. Outcome Measures

Based on the parameters used in the model, the model generates the following outcome measures for comprehensive exams, routine vision screenings, and usual eye care:

Effectiveness of exam/screening/usual eye care
- Proportion of amblyopia cases detected
- Proportion of amblyopia cases with initial contact with optometrist/ophthalmologist
- Proportion of amblyopia cases treated
- Proportion of amblyopia cases successfully treated
- Proportion of false positive exams

Costs
- Costs of initial exam/screening
- Costs of subsequent eye exams (received as part of usual eye care)
- Costs of treating amblyopia
- Costs associated with false positive exams/screenings
- Total cost

Utility values (Quality-adjusted life years)
- Present discounted value of expected lifetime utility (QALYs) with comprehensive exams
- Present discounted value of expected lifetime utility (QALYs) with vision screening
- Present discounted value of expected lifetime utility (QALYs) with usual eye care

Cost effectiveness comparisons
- Difference in quality adjusted life years: Comprehensive exams vs. usual eye care
- Difference in quality adjusted life years: Comprehensive exams vs. vision screening
- Cost per quality adjusted life year: Comprehensive exams (vs. usual eye care)
- Cost per quality adjusted life year: Comprehensive exams (vs. vision screening)

Population statistics
- Total costs (for exams, screening, treatment, false positive follow-up care)
- Number of cases of amblyopia in the exam/screening population
- Number of cases of amblyopia detected
- Number of cases of amblyopia treated
- Number of cases of amblyopia successfully treated
- Cost per case identified
- Cost per case treated
- Cost per case successfully treated
4. Results

4.1. Base-Case Analysis

Detection and Treatment of Amblyopia

Given the higher sensitivity and higher treatment rates associated with comprehensive exams, children with amblyopia are more likely to have this condition detected and treated if they have a preschool comprehensive exam instead of a vision screening.

- Using the base-case parameters, comprehensive exams detect 95 percent of children with amblyopia in the initial period compared to 65 percent of amblyopia cases for children with an initial vision screening and 24 percent of amblyopia cases under usual eye care (Table 5).

- Because comprehensive exams are performed by an eye care professional, all children with amblyopia detected as part of a comprehensive exam (including exams provided as part of usual eye care) have an initial contact with an optometrist or ophthalmologist. This is not the case for vision screenings. Previous studies estimate that only between 40 and 75 percent of those who fail a vision screening have a follow-up visit with an eye care professional. Combined with the sensitivity of vision screenings, the implication is that less than 40 percent of children with amblyopia visited an eye care professional following a vision screening.

- Using the base-case parameter values, we estimate that 76 percent of children with amblyopia who have a comprehensive exam will be treated for the condition in the initial period, compared to 31 percent of children with an initial vision screening and 19 percent of those under usual eye care. Note that additional cases of amblyopia will be detected and treated in subsequent periods, although the probability of successful treatment decreases with age.

- The proportion of children whose amblyopia is successfully treated in the initial period is considerably higher for those with a preschool comprehensive exam (57 percent) than for those with a vision screening (23 percent), or those who do not participate in either an exam or screening program (14 percent).

- Because of the lower specificity of vision screenings, the likelihood of a false positive referral is higher for vision screenings than for comprehensive exams. These false positive referrals generate additional costs but no benefits in terms of treating amblyopia.

The model also considers the patterns of usual eye care that follow a preschool comprehensive exam or vision screening. Under these patterns of usual eye care, almost all children with amblyopia have the condition detected by age 10 (the latest age at which we assumed that amblyopia could be successfully treated). Some have amblyopia detected more than once as a result of not seeking treatment for amblyopia the first time it is detected. Note that, while the model allows for amblyopia to be detected more than once, we assume that amblyopia can only be treated once—if the treatment fails, then our model assumes that the amblyopia is not treatable.
• By age 10, almost 98 percent of those who received a preschool comprehensive exam had been treated for amblyopia, as had almost 95 percent of those with a preschool vision screening and 77 percent of those who received usual eye care (Table 6).

• By age 10, the initial period difference in the percentage of amblyopia cases successfully treated has been narrowed, given that patterns of usual eye care are invariant to whether a child had a preschool exam or vision screening. However, given that the probability of successful treatment decreases with age, this difference is not eliminated entirely. By age 10, among those with an initial comprehensive exam, 68 percent of amblyopia cases are successfully treated, compared to 56 percent of those with an initial vision screening, and 45 percent of those treated under usual eye care only.

• The costs associated with comprehensive exams (including treatment for amblyopia and costs of subsequent eye exams) is $169, compared to $102 for vision screening and $80 for usual eye care (Table 7).

While there is certainly disagreement about the magnitude of the difference, few would disagree that amblyopia is more likely to be detected and treated if a child has a comprehensive exam performed by an optometrist or ophthalmologist than if they have a vision screening that is not performed by an eye care professional. In our model, given the higher sensitivity and referral rates of comprehensive exams, it is a mathematical certainty that comprehensive exams will result in the successful treatment of more cases of amblyopia than vision screenings. The key question, addressed in the next section, is whether these additional cases of amblyopia that are detected and treated offset the higher costs of comprehensive exams.

Table 5: Base-Case Parameters

<table>
<thead>
<tr>
<th>Measure</th>
<th>Comprehensive Eye Exams</th>
<th>Vision Screening</th>
<th>Usual eye care</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent of amblyopia cases detected</td>
<td>95.0%</td>
<td>65.0%</td>
<td>23.8%</td>
</tr>
<tr>
<td>Percent of amblyopia cases with initial contact with optometrist/ophthalmologist</td>
<td>95.0%</td>
<td>39.0%</td>
<td>23.8%</td>
</tr>
<tr>
<td>Percent of amblyopia cases treated</td>
<td>76.0%</td>
<td>31.2%</td>
<td>19.0%</td>
</tr>
<tr>
<td>Percent of study population with false positive referral</td>
<td>2.0%</td>
<td>9.8%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Percent of amblyopia cases untreated</td>
<td>24.0%</td>
<td>68.8%</td>
<td>81.0%</td>
</tr>
<tr>
<td>Percent of amblyopia cases successfully treated</td>
<td>57.0%</td>
<td>23.4%</td>
<td>14.3%</td>
</tr>
</tbody>
</table>

Based on base case parameters described in Table 4.

*Source: Abt Associates, 2004*
Table 6:
Base-Case Parameters
Performance of Comprehensive Exams, Vision Screening, and Usual Eye Care By Age 10

<table>
<thead>
<tr>
<th>Measure</th>
<th>Comprehensive Eye Exams</th>
<th>Vision Screening</th>
<th>Usual eye care</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent of amblyopia cases treated</td>
<td>98.25%</td>
<td>94.98%</td>
<td>77.12%</td>
</tr>
<tr>
<td>Percent of amblyopia cases successfully treated</td>
<td>68.31%</td>
<td>55.82%</td>
<td>45.27%</td>
</tr>
</tbody>
</table>

Based on base case parameters described in Table 4.

Source: Abt Associates, 2004

Table 7:
Base-Case Parameters
Costs Associated With Comprehensive Exams, Vision Screenings, and Usual Eye Care

<table>
<thead>
<tr>
<th>Cost</th>
<th>Comprehensive Eye Exams</th>
<th>Vision Screening</th>
<th>Usual eye care</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs of initial exam/screening</td>
<td>$85.00</td>
<td>$20.00</td>
<td>$0.00</td>
</tr>
<tr>
<td>Costs of subsequent eye exams (i.e., exams received as part of usual eye care)</td>
<td>$46.66</td>
<td>$47.01</td>
<td>$55.93</td>
</tr>
<tr>
<td>Costs associated with false positive exams/screenings</td>
<td>$1.96</td>
<td>$5.61</td>
<td>$0.77</td>
</tr>
<tr>
<td>Costs of treating amblyopia</td>
<td>$35.18</td>
<td>$29.18</td>
<td>$23.67</td>
</tr>
<tr>
<td>Total costs</td>
<td>$168.81</td>
<td>$101.80</td>
<td>$80.37</td>
</tr>
</tbody>
</table>

Based on base case parameters described in Table 4.

Source: Abt Associates, 2004

Population Statistics

Given an exam/screening population of 3.96 million (based on the age 4 population based on figures from the U.S. Census Bureau), the total costs of preschool exams for all children is $337 million, compared to $79.3 million for vision screenings (using the base case parameter values) (Table 8). Including treatment costs, comprehensive exams cost $458 million and a vision screening program costs $129 million. For this additional $329 million investment, we estimate that an additional 27,000 cases of amblyopia will be detected and 33,000 additional cases successfully treated. Including both exam/screening and treatment costs, the cost per case successfully treated is $8,113 for comprehensive exams and $5,567 for vision screening.

While it is clear that, under all reasonable scenarios, vision screenings cost less per successful treatment than comprehensive exams, this is not what is relevant in assessing the overall cost effectiveness of comprehensive exams. What is relevant is whether the additional benefits associated with the 33,000 additional cases of amblyopia that our model suggests would be successfully treated if all children had a preschool eye exam are worth the additional $329 million that the exams and treatment would cost—given our model results this is a cost of about $9,886 per each additional case of amblyopia that is successfully treated. From an economic perspective, society should increase its investments in preschool eye care until the costs of these investments outweigh the benefits (which depend on the value placed on healthy vision for children) that result from these exams.
### Table 8
**Base-Case Parameters**

**Population Statistics for Comprehensive Eye Exams and Vision Screenings**

<table>
<thead>
<tr>
<th>Measure</th>
<th>Comprehensive Exams</th>
<th>Vision Screenings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of screening population*</td>
<td>3,965,103</td>
<td>3,965,103</td>
</tr>
<tr>
<td>Exam/screening costs</td>
<td>$337,033,755</td>
<td>$79,302,060</td>
</tr>
<tr>
<td>Total costs*</td>
<td>$458,401,593</td>
<td>$129,126,751</td>
</tr>
<tr>
<td>Number of cases of amblyopia in screening population</td>
<td>99,128</td>
<td>99,128</td>
</tr>
<tr>
<td>Number of cases of amblyopia detected by initial exam/screening</td>
<td>94,171</td>
<td>64,433</td>
</tr>
<tr>
<td>Number of cases of amblyopia treated</td>
<td>75,337</td>
<td>30,928</td>
</tr>
<tr>
<td>Number cases of amblyopia successfully treated</td>
<td>56,503</td>
<td>23,196</td>
</tr>
<tr>
<td>Exam/screening costs per number treated for amblyopia</td>
<td>$4,473.68</td>
<td>$2,564.10</td>
</tr>
<tr>
<td>Exam/screening costs per number successfully treated for amblyopia</td>
<td>$5,964.91</td>
<td>$3,418.80</td>
</tr>
<tr>
<td>Total costs per number successfully treated for amblyopia</td>
<td>$8,112.91</td>
<td>$5,566.80</td>
</tr>
</tbody>
</table>

*: Defined as the number of 4 year old children in the United States based on figures from the U.S. Census Bureau.

* Including screening/exam and treatment costs in the initial period only.

Based on base case parameters described in Table 4.

**Source:** Abt Associates, 2004

---

### Cost per QALY

Given base case assumptions about the performance of comprehensive exams and vision screenings, and the utility values assigned to different health states, comprehensive exams result in an average increase of 0.0039 QALYs relative to vision screenings and an additional 0.0068 QALYs relative to usual eye care (Table 9). The incremental costs of comprehensive exams were $71.98 relative to vision screenings and $88.44 relative to usual eye care. The cost per QALY for comprehensive exams was $18,390 relative to vision screenings and $12,985 relative to usual eye care.

There is no single accepted standard about the specific cost per QALY, interventions with marginal cost effectiveness ratios of $50,000 or less are generally accepted as reasonable expenditures and interventions with a cost effectiveness ratio of less than $20,000 are considered to be highly cost effective. Given these thresholds and our base case parameters, preschool comprehensive exams appear to be highly cost effective relative to either vision screenings or to no formal screening program.
Using our base model parameters, if society is willing to pay $18,390 to gain an additional QALY for a preschool child, then the policy implication of this study is that comprehensive exams instead of vision screenings should be provided to children prior to entering school.

The primary reason for this result is that, using the base case parameters, treatment for amblyopia is highly cost effective. The costs of treating amblyopia are estimated to be around $1,600. Because children benefit from the treatment over a long period of time, the gain in terms of QALYs associated with successful treatment of amblyopia are relatively high. Using our utility values, a lifetime with amblyopia has about 1.2 fewer discounted QALYs than a lifetime with no amblyopia-caused visual impairments. Given that amblyopia costs about $1,600 to treat and has a 75 percent chance of success if treatment is started early, our model parameters suggest that the cost per QALY for the actual treatment (excluding detection costs) is about $1,800. Membreno et al. found that the dollars per QALY for treatment of amblyopia (ignoring screening and exam costs) was $2,281, which is similar to our estimate. This is a remarkably cost effective treatment given our base case assumptions. The cost effectiveness of comprehensive exams is largely because exams result in a higher proportion of children receiving the highly cost effective treatment for amblyopia than vision screening programs or usual eye care.

Our model reflects the higher costs of comprehensive exams, but these higher costs are offset by the gains (in terms of additional QALYs) that result from the additional children who are successfully treated as a result of having a comprehensive exam. As described in the next section, this result is robust across different assumptions about the prevalence of amblyopia in the study population, the costs of comprehensive exams, and the relative performance of exams.

---

5 This is calculated by dividing the 1.19 additional QALYs associated with healthy vision by the $2,147 expected cost of successfully treating a case of amblyopia (The $1,611 treatment cost is the expected cost of successfully treating 0.75 cases of amblyopia given the treatment success probabilities.)
4.2. Sensitivity Analyses

Given the uncertainty over the values of most model parameters, we tested the sensitivity of our findings to the underlying parameter values.

Univariate Sensitivity Analyses

Figures 1 and 2 and Table 10 show the incremental cost effectiveness ratios resulting from changes in individual model parameters. The bars in these figures show the range of cost effectiveness estimates using the low and high values of the parameters that we tested. Parameters with long bars are those for which results are most sensitive (i.e., changes in the parameter value have a large impact on estimated cost effectiveness.) Results were robust to assumptions about the values of most, but not all, model parameters:

- Assumptions about the performance of comprehensive exams and vision screenings (sensitivity, specificity, referral rate, compliance) had relatively little impact on estimates of cost effectiveness, given the range of parameter values that we examined (Figure 1).

- Results are somewhat sensitive to assumptions made about referrals to eye care professionals associated with vision screenings. At the maximum value that we tested for the referral rate, the cost per QALY was $21,962, compared with $15,878 using the lower bound estimate of this parameter.

- The biggest driver of model results is assumptions made about the utility associated with amblyopia. If the impact of untreated amblyopia on quality of life is smaller, then the estimated cost per quality adjusted life year becomes larger. For example, if we assume that the utility of amblyopia is 0.92 (vs. the 0.96 base case assumption), then cost/QALY for exams relative to screenings is $8,702; if the utility of amblyopia is 0.99, then this cost/QALY increases to $111,461 and comprehensive exams would not meet the commonly used threshold for cost effectiveness (Figure 2). Figure 4 shows how results change with different assumptions about the utility associated with amblyopia. The lack of information
available on the impact of amblyopia on quality of life is a clear limitation of our analysis—particularly given the sensitivity of results to this parameter.

- Results are sensitive to assumptions about the prevalence of amblyopia in the population. If the prevalence is only 1 percent, then the cost per QALY for exams relative to vision screenings is $43,821 (vs. $18,390 in the base case and using the base parameters for other model inputs); if the prevalence is 4 percent, then the cost/QALY is only $12,033 (Figure 1). Figure 3 provides additional details on how the cost/QALY for exams relative to vision screenings changes based on assumptions about the prevalence of amblyopia.

- Results were invariant to assumptions made about the utility values and prevalence of amblyopia-caused bilateral impairment (see Table 10).

- If the proportion of children assumed to receive eye exams under usual eye care is assumed to be 20 percent (and 50 percent for those with amblyopia), then the cost effectiveness of comprehensive exams relative to vision screenings increases to 39,981. If these probabilities are reduced to 5 percent and 12.5 percent, respectively, then the incremental cost effectiveness of exams decreases to $11,241.

- Results were influenced somewhat depending on the costs of comprehensive exams. If the cost of exams increases from $65 to $105, the cost/QALY of exams relative to vision screenings increases from $13,222 to $23,559. Even with the maximum value assumed for the costs of comprehensive exams, however, exams meet the threshold for cost effectiveness.

- If the costs of treating amblyopia were reduced by 50 percent, the cost/QALY for exams relative to screenings decreases from $18,390 to $17,623. If treatment costs double, this cost effectiveness ratio increases to $19,157 (Table 2). The impact of changes in treatment costs is rather small because of the relatively low proportion of children who require treatment for amblyopia.

- The future discount rate also influences the results. Because the costs associated with amblyopia detection and treatment are realized early in life, they are not sensitive to the discount rate. But improvements in quality of life associated with healthy vision are realized all through life and a higher discount rate on future utility reduces the cost effectiveness of comprehensive eye exams. Konig and Barry used a default discount rate of 0.05, and this discount rate increases the cost per QALY of comprehensive exams to $27,110 relative to vision screenings. A lower discount rate of 0.01 lowers the cost per QALY for comprehensive exams to $10,700. Figure 5 provides additional details on the sensitivity of results to assumptions about the discount rate on future costs and utility.

- While not part of the basic model structure, we also considered a scenario in which the costs of comprehensive exams were $125 instead of $85. The higher costs in this scenario reflect the costs to society associated with the estimates of inappropriate eyeglass prescription in comprehensive eye exams identified by Donahue (assuming that 18 percent of preschool children inappropriately receive eyeglasses at an average cost of $200). This increased the cost per QALY of comprehensive exams to $28,727 relative to vision screening and $18,300 relative to usual eye care. If there is inappropriate eyeglass prescription associated with
comprehensive eye exams, then this obviously reduces the cost effectiveness of these exams, but, the decrease would not so large that it changes the basic conclusion of this study—the benefits of the detection and treatment of amblyopia associated with comprehensive eye exams outweigh the measure of exam costs that includes the costs of inappropriate utilization. In fact, the cost per QALY of comprehensive exams relative to vision screenings does not reach the generally accepted $50,000 threshold unless comprehensive exams cost $205 or more (using base case values for other parameters).
Figure 1: Sensitivity Analyses for Comprehensive Exams and Vision Screenings: Cost Per Quality Adjusted Life Year For Minimum and Maximum Parameter Values
Figure 2: Sensitivity Analyses for Comprehensive Exams and Vision Screenings:
Cost Per Quality Adjusted Life Year For Minimum and Maximum Parameter Values

- Discount Rate
- Treatment costs
- Screening costs
- Exam costs
- Amblyopia utility
- Bi-lateral utility
- Treatment utility
Figure 3: Sensitivity Analyses For Comprehensive Exams Relative to Vision Screenings: Sensitivity to Prevalence of Amblyopia
Figure 4: Sensitivity Analyses For Comprehensive Exams Relative to Vision Screenings: Sensitivity to Utility of Amblyopia
Figure 5: Sensitivity Analyses For Comprehensive Exams Relative to Vision Screenings:
Sensitivity to Patterns of Usual Care

Cost/QALY

Percent with eye exam each year as part of usual care
### Table 10
Univariate Sensitivity Analyses for Comprehensive Eye Exams

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range Tested</th>
<th>Relative to Vision Screening</th>
<th>Relative to Usual eye care</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Exam sensitivity</td>
<td>90%</td>
<td>100%</td>
<td>$20,052</td>
</tr>
<tr>
<td>Exam specificity</td>
<td>93%</td>
<td>100%</td>
<td>$18,729</td>
</tr>
<tr>
<td>Screening sensitivity</td>
<td>50%</td>
<td>80%</td>
<td>$16,044</td>
</tr>
<tr>
<td>Referral rate</td>
<td>40%</td>
<td>100%</td>
<td>$15,198</td>
</tr>
<tr>
<td>Adherence</td>
<td>70%</td>
<td>90%</td>
<td>$20,269</td>
</tr>
<tr>
<td>Effectiveness of treatment started early</td>
<td>60%</td>
<td>90%</td>
<td>$20,548</td>
</tr>
<tr>
<td>Usual eye care visit rate</td>
<td>5%</td>
<td>15%</td>
<td>$12,043</td>
</tr>
<tr>
<td>Usual eye care: Visit rate for those with amblyopia</td>
<td>10%</td>
<td>40%</td>
<td>$11,241</td>
</tr>
<tr>
<td>Prevalence</td>
<td>1%</td>
<td>4%</td>
<td>$43,821</td>
</tr>
<tr>
<td>Probability of blindness</td>
<td>(see Table 4)</td>
<td>$18,401</td>
<td>$18,370</td>
</tr>
<tr>
<td>Amblyopia utility</td>
<td>0.92</td>
<td>0.995</td>
<td>$8,702</td>
</tr>
<tr>
<td>Bi-lateral utility</td>
<td>0.71</td>
<td>0.85</td>
<td>$8,702</td>
</tr>
<tr>
<td>Treatment utility</td>
<td>0.92</td>
<td>1.0</td>
<td>$20,767</td>
</tr>
<tr>
<td>Exam costs</td>
<td>$50</td>
<td>$120</td>
<td>$13,222</td>
</tr>
<tr>
<td>Screening costs</td>
<td>$10</td>
<td>$30</td>
<td>$20,945</td>
</tr>
<tr>
<td>Treatment costs</td>
<td>(see Table 4)</td>
<td>$17,623</td>
<td>$19,157</td>
</tr>
<tr>
<td>Discount rate</td>
<td>0.01</td>
<td>0.05</td>
<td>$10,700</td>
</tr>
</tbody>
</table>

Source: Abt Associates, 2004

### Multivariate Simulation Analyses (Monte Carlo Simulations)

Using the range of values for model parameters described in Table 4, we ran 10,000 simulations to estimate the cost effectiveness of comprehensive exams relative to vision screenings. Reflecting the uncertainty that exists for the model parameters, there was considerable variation in the estimated cost per QALY. In most of the simulations, however, the cost per QALY for comprehensive exams was below the conventional $50,000 threshold, suggesting that our basic conclusion that comprehensive exams for preschool children was relatively robust.

- In 95 percent of the simulations, the cost per QALY was between $2,257 and $47,302. This is a measure of the 95 percent confidence interval of model findings. The 90 percent confidence interval is $3,847 to $91,299. Figure 6 reports the distribution of cost per QALYs that were observed in the simulations.
• In 87 percent of the simulations, the cost per QALY for comprehensive exams relative to vision screenings was less than $50,000. It was less than $25,000 in 69 percent of the simulations, and less than $15,000 in almost 50 percent of the simulations.

• A major source of variation in results was uncertainty regarding the utility of amblyopia. Among simulations in which this utility was 0.98 or less, the 95 percent confidence interval was $2,194 - $109,342, and the cost per QALY was greater than $50,000 for only 8.4 percent of the simulations. For simulations in which the utility associated with amblyopia was higher than 0.98, the median cost per QALY was $40,958 and the cost per QALY was greater than $50,000 in 40 percent of simulations.

• Results were also sensitive to assumptions about the prevalence of amblyopia in the study population. For simulations in which the prevalence was 2 percent or higher, the 95 percent confidence interval was $1,933- $109,524, and the cost per QALY was greater than $50,000 in 8.1 percent of the simulations. In simulations for which the prevalence of amblyopia was less than 2 percent, the cost per QALY was greater than $50,000 in 22 percent of the simulations.

• Given the range of estimates used for the sensitivity of comprehensive exams and visions screenings, the simulations differed with respect to the relative performance of comprehensive exams and screenings. In simulations where exams had sensitivity that was .4 or more greater than that of vision screenings, the median cost per QALY was $13,762; in simulations in which this difference was 0.2 or less the median cost per QALY was $15,070.

• Results were only moderately sensitive to the costs of comprehensive exams and vision screenings. Multivariate regression analyses indicated that each $1 increase in the cost of comprehensive exams was associated with an increase of almost $300 in the estimated cost per QALY; each $1 increase in the cost of vision screenings was associated with a $241 reduction in the cost per QALY. For simulations in which the cost of comprehensive exams was $95 or higher, the average cost per QALY was $24,615 and the 95 percent confidence interval was $2,373 - $212,707.

• Assumptions about the effectiveness of treatment for amblyopia had an obvious effect on results. In scenarios in which the probability of successful treatment was less than 70 percent, the median cost per QALY was $17,736; in simulations where the probability of successful treatment was 80 percent or higher, the median cost per QALY was $10,337.

• Results were also somewhat sensitive to assumptions made about the discount rate on future utilities and costs. For simulations in which the discount rate was relatively low (0.02 or lower suggesting that future utility was valued at close to the rate of present utility, the median cost per QALY was $9,743, compared to a median cost per QALY of $18,714 for simulations in which future utility was discounted at a relatively high rate (0.04 or higher).

• The impact of changes in other model parameters (specificity, probability and utility associated with amblyopia-caused bilateral impairment, treatment costs) were smaller and changes in these values do not change the study’s basic conclusions.
Figure 6: Cost Effectiveness of Comprehensive Eye Exams Relative To Vision Screenings:
Monte Carlo Simulation Analysis of Cost per QALY
5. Summary and Conclusions

Overview of Study Methodology

We developed a cost effectiveness model for analyzing the cost effectiveness of comprehensive eye exams relative to vision screenings and patterns of usual eye care in the absence of a formal screening program. We assessed cost effectiveness using cost-utility analysis, a method of economic evaluation that analyzes the cost effectiveness of interventions based on the cost per Quality-Adjusted Life Year (QALY). The marginal cost effectiveness of comprehensive eye exams (relative to vision screening or usual eye care) depends on the costs of the intervention and the quality (i.e., utility) associated with years lived with a visual impairment. This is an approach that has been used in many other studies to compare different interventions for the detection or treatment of given diseases.

Given an initial prevalence of amblyopia in the study population, the model takes into account the relative performance (sensitivity, specificity, receipt of appropriate follow-up treatment) of comprehensive exams and vision screenings, the probability that treatment is successful, the costs of exams, screenings, and treatment, the utility values associated with healthy vision, amblyopia, and amblyopia-caused bilateral impairment, and patterns of treatment under usual eye care.

Parameters for the model were based on a comprehensive review of relevant studies in the literature. The study focused on amblyopia, the only condition for which the literature was adequate for developing model parameters. While there was no consensus in the literature for any model parameter, we were able to develop a range of model parameter values and developed a base-case that represents our best estimate of all parameters using the literature and a panel of experts. We used sensitivity analyses to investigate the robustness of results to different assumptions about underlying model parameters.

Overview of Study Findings

Using our base case estimates of all model parameters, the evidence supporting the cost effectiveness of comprehensive exams is strong and compelling. Using base case parameters, the incremental cost effectiveness (in terms of cost per QALY) of comprehensive exams was $18,390 relative to vision screening and $12,985 relative to usual eye care in the absence of a screening program. This is well below the conventional thresholds used to determine whether a particular intervention is a reasonable expenditure.

We used sensitivity analyses to examine how the factors used in the model might make exams more or less cost effective. Under a wide range of scenarios, comprehensive eye exams appear to be highly cost effective relative to either vision screening programs or usual eye care. While there are significant gaps in the literature that limit the reliability of study findings, this basic conclusion was robust across the entire range that we considered for most model parameters, suggests that policymakers may wish to give serious consideration to programs that would increase the number of preschool children that receive a comprehensive eye exam and educating them about the important differences between comprehensive exams and vision screenings.
The study’s conclusions are driven to a large extent by the finding that treatment for amblyopia is highly cost effective. The cost per QALY associated with amblyopia treatment (separate from detection of amblyopia) was only about $1,800, suggesting that the screening/exam program that gets the most children into treatment is the most cost effective intervention, particularly given the cost difference between exams and screening programs and the prevalence of amblyopia in the population. Given our model parameters, the additional costs associated with comprehensive exams are offset by the gains that result from the additional children who are successfully treated due to comprehensive exams.

**Comparison to Other Medical Interventions**

Our measure of cost effectiveness, cost per QALY, is a measure that has been used in many other cost effectiveness studies. This permits comparison of the cost effectiveness of comprehensive eye exams relative to other medical interventions. Table 11 summarizes the results of some other cost effectiveness studies (ophthalmic interventions are listed in bold). While there are considerable differences in the study population and methods used by these studies, comparison of our results suggests that the cost effectiveness of comprehensive exams compares favorably to that of other medical interventions.

---

6 For a detailed summary of all cost effectiveness studies conducted between 1976-2001, see the Comprehensive Table of Cost Utility Ratios, 1976-2001, prepared by the Harvard Center for Risk Analysis, Harvard School of Public Health (http://www.hsph.harvard.edu/cearegistry/)
Table 11:
Cost Effectiveness Of Other Medical Interventions:
Cost per Quality Adjusted Life Year From Other Published Studies

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Cost per QALY†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liver transplantation$^{93}$</td>
<td>$350,000</td>
</tr>
<tr>
<td>Regulation against using a cell phone while driving$^{94}$</td>
<td>$350,000</td>
</tr>
<tr>
<td>Central retinal artery occlusion (paracentesis)$^{95}$</td>
<td>$345,000</td>
</tr>
<tr>
<td>Annual retinopathy screening for 45-y.o. diabetes patient with good control$^{93}$</td>
<td>$231,000</td>
</tr>
<tr>
<td>Photodynamic AMD therapy (20/200 vision)$^{93}$</td>
<td>$174,000</td>
</tr>
<tr>
<td>Elective repeat cesarean birth (vs. vaginal birth)$^{95}$</td>
<td>$120,000</td>
</tr>
<tr>
<td>Lung transplantation program vs. no program$^{96}$</td>
<td>$120,000</td>
</tr>
<tr>
<td>Photodynamic AMD therapy (20/40 vision)$^{97}$</td>
<td>$87,000</td>
</tr>
<tr>
<td>PVR eye surgery$^{93}$</td>
<td>$80,000</td>
</tr>
<tr>
<td>Dual-side air bags$^{98}$</td>
<td>$76,000</td>
</tr>
<tr>
<td>Diabetes screening (vs no screening, all individuals over age 25)$^{99}$</td>
<td>$67,000</td>
</tr>
<tr>
<td>ESRD treatment, including dialysis and transplants (vs patients with ESRD)$^{100}$</td>
<td>$67,000</td>
</tr>
<tr>
<td>Hepatitis A vaccination (vs. no vaccination)$^{101}$</td>
<td>$54,000</td>
</tr>
<tr>
<td>Supplementary childhood immunization programs developed by CDC (increase immunization rate from 55 percent to 90 percent)$^{102}$</td>
<td>$51,000</td>
</tr>
<tr>
<td>Heart transplantation (vs. optimal conventional treatment) for patients needing heart transplants$^{103}$</td>
<td>$51,000</td>
</tr>
<tr>
<td>Annual retinopathy screening for 45-y.o. diabetes patient with poor control$^{93}$</td>
<td>$44,000</td>
</tr>
<tr>
<td>Chemotherapy (for 60 year old with breast cancer)$^{104}$</td>
<td>$41,000</td>
</tr>
<tr>
<td>One-time screening for depression (40 year old primary care patients)$^{105}$</td>
<td>$35,000</td>
</tr>
<tr>
<td>Driver-side air bags$^{98}$</td>
<td>$30,000</td>
</tr>
<tr>
<td>Intensive insulin vs. standard therapy in patients with diabetes mellitus, post myocardial infarction$^{106}$</td>
<td>$28,000</td>
</tr>
<tr>
<td>School-based tobacco prevention program (assumes 30% smoking reduction, dissipates over 4 years)$^{107}$</td>
<td>$22,000</td>
</tr>
<tr>
<td>Breast cancer screening every two years vs no screening past age 69 for 70-75 year old women$^{104}$</td>
<td>$21,000</td>
</tr>
<tr>
<td>Cochlear implant for deaf individual$^{108}$</td>
<td>$20,000</td>
</tr>
<tr>
<td>Hypertension screening (vs. no screening for asymptomatic 60 year old woman)$^{109}$</td>
<td>$19,000</td>
</tr>
<tr>
<td>Universal vaccination against Hepatitis A vs. initial screen for presence of preventive antibody with vaccination if susceptible$^{110}$</td>
<td>$14,000</td>
</tr>
<tr>
<td>Bone marrow transplantation$^{111}$</td>
<td>$11,000</td>
</tr>
<tr>
<td><strong>Laser therapy (for visual loss secondary to branch retinal vein occlusion)</strong>$^{94}$</td>
<td><strong>$6,100</strong></td>
</tr>
<tr>
<td>Universal cancer screening program (vs. no screening program)$^{112}$</td>
<td>$5,200</td>
</tr>
<tr>
<td><strong>Cataract surgery</strong>$^{113}$</td>
<td><strong>$4,500</strong></td>
</tr>
<tr>
<td>Screening and treatment programs for diabetic eye disease (for those with non-insulin dependent diabetes mellitus)$^{106}$</td>
<td>$2,700</td>
</tr>
</tbody>
</table>

†In 2002 dollars

The source for many of these studies is the Harvard Center for Risk Analyses, Harvard School of Public Health. Comprehensive Table of Cost Utility Ratios, 1976-2001 http://www.hsph.harvard.edu/cearegistry/
Study Limitations

In addition to limitations resulting from gaps in our knowledge about the performance of vision screenings and comprehensive exams and the treatment of amblyopia, there are several other important study limitations:

- The study focuses on the cost effectiveness of comprehensive exams for pre-school children but does not address important questions related to the feasibility of requiring these exams, such as the adequacy of the optometrist and ophthalmologist workforce to furnish these exams. Of course, before addressing these types of feasibility concerns, it is important to investigate whether comprehensive exams are a cost effective intervention. If they are not, then issues related to implementing comprehensive exams for preschool children become moot.

- For some important parameters, however, particularly the quality of life (i.e., utility value) associated with amblyopia, there is very limited guidance in the literature. This lack of data is a clear limitation of our analysis. Assumptions made about the utility (or quality of life) associated with untreated amblyopia have a large impact on our estimates. Following Konig and Barry, we assumed that this utility value was 0.96. But previous studies offer mixed evidence regarding the impact of untreated amblyopia on quality of life—according to Snowdon and Stewart-Brown27, the existing literature does not support the need to treat amblyopia, although this is related more to limitations in the method used in previous studies than in a belief that untreated amblyopia is not potentially harmful. Model results are very sensitive to assumptions about the utility value associated with amblyopia—as this utility value increases the estimated cost per QALY becomes larger. The reduced risk of blindness that results from treatment of amblyopia is not large enough to justify the costs of exams (or screening programs for that matter).

- The model relies on assumptions about the “usual eye care” that children would receive without a comprehensive exam or vision-screening program. In addition to assumptions about the visit rate to optometrists/ophthalmologists for healthy children, we make assumptions about the additional probability of an exam under usual eye care for those with amblyopia (i.e., because they are referred by a pediatrician). We have not identified any literature that is useful for refining the base value of this parameter, but it has a large impact on our results.

- The model focused only on amblyopia, but there are other important visual disorders that may be detected and treated with greater frequency in comprehensive exams than in vision screenings. Since the model includes all of the costs of exams but may not consider all their benefits, it may be that the results reported in this study somewhat understate the actual cost effectiveness of comprehensive exams. There is insufficient literature, however, to support extending the model beyond amblyopia.

In the course of the study, we identified several important gaps in our knowledge about the performance of vision screenings and comprehensive exams, and the treatment for amblyopia. Most notable are gaps in knowledge about the impact of amblyopia on quality of life, the treatment costs associated with amblyopia, and the relative performance of comprehensive exams and vision.
screenings. It was beyond the scope of this study to address any of these gaps, but future research that addresses these topics would help us to understand better the cost effectiveness of comprehensive exams.

Discussion

Despite important gaps in the literature, the study’s results suggest that comprehensive eye exams may be a cost effective intervention for pre-school children. Comprehensive exams almost certainly result in more cases of amblyopia being detected than do vision screenings, and treatment for amblyopia is highly cost effective, using the most reliable available data on the costs of treatment and the utility value associated with amblyopia.

While the thresholds for what makes a particular intervention cost effective are controversial, interventions with costs per QALY in the range that we found (a cost per QALY of $18,390 for comprehensive exams relative to vision screenings) are generally considered to be highly cost effective and thus a good use of scarce health care resources.

Comprehensive exams cost considerably more than vision screenings, but our results suggest that the higher costs associated with them are more than offset by the gains that result from the additional children who are successfully treated as a result of having a comprehensive exam. From an economic perspective, it is this comparison of marginal benefits and costs, not a comparison of average costs per case diagnosed or treated, that is relevant for assessing the desirability of comprehensive eye exams. Analysis of the costs of comprehensive exams without consideration of the potential benefits is not appropriate for determining the desirability of comprehensive exams.

On the basis of the results of our cost-effectiveness analysis, should policymakers follow Kentucky in requiring comprehensive exams for preschool children? It was beyond the scope of this report to examine issues related to the feasibility of such a requirement, so we are not able to answer this question. We did, however, find that comprehensive exams are highly cost effective relative to other health care interventions and that programs that increase the proportion of children with amblyopia who receive the appropriate follow-up care seem to be very cost effective.

Our findings suggest that policymakers should consider programs that would increase the proportion of preschool children who receive a comprehensive exam, potentially including an exam requirement. We have made our best estimate at the values of all model parameters, based on an exhaustive review of the relevant literature. There are, however, important limitations in the studies that we used to generate model parameters, and these limitations decrease our confidence in our findings. In particular, there are gaps in our understanding of the impact of amblyopia on quality of life and the performance of comprehensive exams and vision screenings. There is a clear need for further research on these topics, and we suggest that, as the results from additional studies become available, that they be incorporated into a revised version of our model so that we can understand how the most recent findings affect our results. Data for even such basic parameters as the prevalence of amblyopia is limited by the non-random nature of the study populations used in most previous studies.
Technical Appendix: Mathematical Description of Model

The model evaluates the cost effectiveness of comprehensive eye exams, relative to vision screenings and patterns of usual eye care in the absence of any exam or screening program using a cost-utility framework. The lifetime value of utility depends on the probability of being in each of the health states in the model and the relative utility of that health state. Note that the utility values for each state and time period are adjusted based on the probability of being alive at that point and the discount rate. Lifetime quality adjusted years for those with a preschool comprehensive eye exam, vision screening, and no participation in an exam or screening program are given by:

Performance Measures: Cost per Quality-Adjusted Life Year

The key measures of the performance of comprehensive exams are the cost per quality-adjusted life year (QALY) of comprehensive exams relative to vision screening or usual eye care:

Cost per QALY for comprehensive exams relative to preschool vision screenings:

\[ (1a) \quad \frac{\text{Cost}_{\text{Exam}} - \text{Cost}_{\text{Screening}}}{\text{QALY}_{\text{Exam}} - \text{QALY}_{\text{Screening}}} \]

Cost per QALY for comprehensive exams relative to usual eye care:

\[ (1b) \quad \frac{\text{Cost}_{\text{Exam}} - \text{Cost}_{\text{Usual}}}{\text{QALY}_{\text{Exam}} - \text{QALY}_{\text{Usual}}} \]

Below, we show the steps used to calculate these key performance measures.

Lifetime Quality-Adjusted Life Years

Lifetime quality adjusted life years depend on the probability of being in each of the health states considered in the model (healthy vision, amblyopia or other unilateral impairment, bilateral impairment that is the result of untreated amblyopia), and the discounted utility values associated with each of these states:

\[ (2a) \quad \text{QALY}_{\text{Exam}} = \sum_{t=1}^{T} \text{Pr(Health}_{\text{Exam},t} \times U_{\text{Health},t} + \text{Pr(Amb}_{\text{Exam},t} \times U_{\text{Amb},t} + \text{Pr(Blind}_{\text{Exam},t} \times U_{\text{Blind},t} \]

\[ (2b) \quad \text{QALY}_{\text{Screen}} = \sum_{t=1}^{T} \text{Pr(Health}_{\text{Screen},t} \times U_{\text{Health},t} + \text{Pr(Amb}_{\text{Screen},t} \times U_{\text{Amb},t} + \text{Pr(Blind}_{\text{Screen},t} \times U_{\text{Blind},t} \]

\[ (2c) \quad \text{QALY}_{\text{Usual}} = \sum_{t=1}^{T} \text{Pr(Health}_{\text{Usual},t} \times U_{\text{Health},t} + \text{Pr(Amb}_{\text{Usual},t} \times U_{\text{Amb},t} + \text{Pr(Blind}_{\text{Usual},t} \times U_{\text{Blind},t} \]

where \( \text{Pr(Health) \) is the probability of not having a visual impairment; \( \text{Pr(Amb) \) is the probability of having amblyopia or another unilateral visual impairment; \( \text{Pr(Blind) \) is the probability of bilateral visual impairment that is related to untreated amblyopia; and \( U_{\text{Health}}, U_{\text{Amb}} \) and \( U_{\text{Blind}} \) are the utility values associated with each of these states. Note that throughout this section, the subscripts Exam, Screen, and Usual are used to indicate the type of preschool vision care that is being modeled.
Lifetime Costs Associated With Childhood Eye Care

The model includes costs associated with the initial preschool comprehensive exam or vision screening, the costs associated with subsequent eye exams received as part of usual eye care between the ages of 4 and 10; and the costs associated with treatment of amblyopia. Note that, for those falsely diagnosed with amblyopia after an initial comprehensive exam or screening who receive follow-up care, costs also include the cost of a follow-up exam at which we assume that the false positive result is detected and there is no further treatment.

\[\text{Total Cost}_{\text{Exam}} = \text{Cost}_{\text{Exam}} + \sum_{i=1}^{T} \text{Treat}_{\text{Exam}} \times \text{Cost}_{\text{Treat Age}}\]

\[\text{Total Cost}_{\text{Screen}} = \text{Cost}_{\text{Screen}} + \sum_{i=1}^{T} \text{Treat}_{\text{Screen}} \times \text{Cost}_{\text{Treat Age}}\]

\[\text{Total Cost}_{\text{Usual}} = \text{Cost}_{\text{Usual}} + \sum_{i=1}^{T} \text{Treat}_{\text{Usual}} \times \text{Cost}_{\text{Treat Age}}\]

Utility Values Associated With Each Health State

At each time period, each of the health states in the model have a utility value that depends on the utility value assigned to the state, the discount rate, and the probability of being alive at that point in time.

\[U_{\text{Health},t} = \frac{(1 - \sum_{i=1}^{t-1} \Pr(\text{Death}_i) \times \text{Utility}_{\text{Health}})}{(1 + \text{Disc})^{t-1}}\]

\[U_{\text{Amb},t} = \frac{(1 - \sum_{i=1}^{t-1} \Pr(\text{Death}_i) \times \text{Utility}_{\text{Amb}})}{(1 + \text{Disc})^{t-1}}\]

\[U_{\text{Blind},t} = \frac{(1 - \sum_{i=1}^{t-1} \Pr(\text{Death}_i) \times \text{Utility}_{\text{Blind}})}{(1 + \text{Disc})^{t-1}}\]

Health State Probabilities

In each period, individuals are in one of these health states:

- **Amblyopia or other unilateral visual impairment.** The probability of amblyopia in any period depends on 1) the prevalence of amblyopia in the population; 2) the proportion of amblyopia cases that have previously been successfully treated; and 3) the incidence of other unilateral visual impairment, which occurs in adulthood.

- **Bilateral visual impairment related to amblyopia.** In each period, the probability of bilateral visual impairment that is related to untreated amblyopia depends on the proportion of the population with amblyopia in the period and the incidence rate of unilateral vision loss in the non-amblyopic eye.

- **Healthy vision.** The probability of having no visual impairment is defined as one minus the probability of having one of the health conditions described above.

Note that, while mortality is not an explicit health state, it enters the model because the health state utility values for each time period are discounted by the probability of being deceased.
Because the probabilities depend on whether amblyopia is successfully treated, which is related to the type of pre-school eye care that the study population receives, the health state probabilities are different for those who receive a comprehensive exam, a vision screening, or usual eye care.

\[
\begin{align*}
[5a] \Pr(Amb_{Exam}) &= \text{Prev} - \sum_{t=1}^{T} \text{Cure}_{Exam} \\
[5b] \Pr(Amb_{Screen}) &= \text{Prev} - \sum_{t=1}^{T} \text{Cure}_{Screen} \\
[5c] \Pr(Amb_{Usual}) &= \text{Prev} - \sum_{t=1}^{T} \text{Cure}_{Usual} \\
[6a] \Pr(Blind_{Exam, Age}) &= \Pr(Amb_{Exam}) \times \Pr(Blindness_{Age}) \\
[6b] \Pr(Blind_{Screen, Age}) &= \Pr(Amb_{Screen}) \times \Pr(Blindness_{Age}) \\
[6c] \Pr(Blind_{Usual, Age}) &= \Pr(Amb_{Usual}) \times \Pr(Blindness_{Age}) \\
[7a] \Pr(Health_{Exam}) &= 1 - \Pr(Amb_{Exam}) - \Pr(Blind_{Exam}) \\
[7b] \Pr(Health_{Screen}) &= 1 - \Pr(Amb_{Screen}) - \Pr(Blind_{Screen}) \\
[7c] \Pr(Health_{Usual}) &= 1 - \Pr(Amb_{Usual}) - \Pr(Blind_{Usual})
\end{align*}
\]

**Performance of Comprehensive Exams and Vision Screenings**

The performance of comprehensive exams depends on the following factors:

- **Prevalence**: This is the proportion of the study population with amblyopia at the beginning of the initial period. (Prev)
- **Sensitivity**: This is the probability of detecting amblyopia (Sensitivity_{Exam}, Sensitivity_{Screen}).
- **Specificity**: This is the probability that a comprehensive exam detects amblyopia when, in fact, no amblyopia is present in the patient is the probability of detecting amblyopia (i.e., the false positive rate) (Specificity_{Exam}, Specificity_{Screen}).
- **Referral rate**: This is the probability that an initial contact is made with an eye care professional following detection of amblyopia. This is separate from longer-term compliance with recommended treatment\(^7\). (Referral_{Exam}, Referral_{Screen}).
- **Adherence/compliance**: This is the rate at which patients follow the recommended treatment for amblyopia (False_{Exam}, False_{Screen}).
- **Treatment success**: This is the probability of successful treatment, for those who comply with treatment recommendations. Following Konig and Barry, this varies based on age. This is

\(^7\) Note that since comprehensive exams are performed by eye care professionals, this probability equals 100% for comprehensive eye exams.
dependent on age but not whether treatment was initiated as a result of a comprehensive exam or a vision screening. \(\text{Success}_{\text{Age}}\).

Based on these factors, we calculate several performance measures:

- **Detection rate**: This depends on the prevalence of amblyopia in the study population and the sensitivity of comprehensive exams. It is the proportion of the study population that have amblyopia detected in the initial period as a result of a preschool exam or vision screening or in a subsequent visit due to eye care received as part of usual eye care \(\text{Detect}_{\text{Exam}}, \text{Detect}_{\text{Screen}}\).

- **False positive rate**: This depends on the prevalence of amblyopia in the study population and the sensitivity of comprehensive exams and vision screenings. It is the proportion of the study population with a false positive exam (i.e., amblyopia is detected when it is really not present) in a given period \(\text{False}_{\text{Exam}}, \text{False}_{\text{Screen}}\).

- **Follow-up care rate**: This is the product of the detection rate and the referral rate. It is the proportion of the study population that has contact with an eye care professional following diagnosis of amblyopia in a comprehensive exam \(\text{Follow}_{\text{Exam}}, \text{Follow}_{\text{Screen}}\).

- **Treatment rate**: This is the proportion of the study population that has treatment for amblyopia detected as result of a preschool comprehensive exam or vision screening, or the exams that occur in subsequent periods as part of usual eye care \(\text{Treat}_{\text{Exam}}, \text{Treat}_{\text{Screen}}\).

- **Cure rate**: This depends on the treatment rate and the probability that treatment is successful. It is the proportion of the study population whose amblyopia is cured as a result of the care that they receive after a diagnosis of amblyopia \(\text{Cure}_{\text{Exam}}, \text{Cure}_{\text{Screen}}\).

Mathematically:

\[
\begin{align*}
\text{[8a]} \quad \text{Detect}_{\text{Exam}} &= \text{Prevalence} \times \text{Sensitivity}_{\text{Exam}} \\
\text{[8b]} \quad \text{False}_{\text{Exam}} &= \text{Prevalence} \times (1 - \text{Specificity})_{\text{Exam}} \\
\text{[8c]} \quad \text{Follow}_{\text{Exam}} &= \text{Detect}_{\text{Exam}} \times \text{Refferal}_{\text{Exam}} \\
\text{[8d]} \quad \text{Treat}_{\text{Exam}} &= \text{Follow}_{\text{Exam}} \times \text{Adherence}_{\text{Exam}} \\
\text{[8e]} \quad \text{Untreat}_{\text{Exam}} &= \text{Prev} - \text{Treat}_{\text{Exam}} \\
\text{[8f]} \quad \text{Cure}_{\text{Exam}} &= \text{Treat}_{\text{Exam}} \times \text{Effectiveness}_{\text{Age}} \\
\end{align*}
\]

The model has an analogous structure for vision screenings.

\[
\begin{align*}
\text{[9a]} \quad \text{Detect}_{\text{Screen}} &= \text{Prevalence} \times \text{Sensitivity}_{\text{Screen}} \\
\end{align*}
\]
Even without a preschool comprehensive exam or vision screening, some children with amblyopia will have the condition detected and treated as a result of the eye care that they have in the absence of a formal screening program. The model includes these patterns of usual eye care, the results of which depend on the proportion of amblyopia cases detected in the preschool period. We allow for the possibility that children with amblyopia are more likely to receive an exam under usual eye care and model all eye care that the child receives between the ages of four and ten. The model includes these parameters:

- **Exam rate under usual eye care**: This is the probability of receiving an eye exam under usual eye care for those without amblyopia. Our assumption is that this rate is independent of exam history in previous periods (Usual_rate).

- **Relative probability of eye exam under usual eye care for those with amblyopia** (Amb_Like)

- **Exam rate under usual eye care for those with amblyopia**: This is the product of the exam rate under usual eye care and the relative probability of an eye exam under usual eye care for those with amblyopia (Usual_rate_amb).

The costs and performance of eye exams received as part of usual eye care is assumed to be the same as for comprehensive eye exams, except that the probability of successfully treating amblyopia decreases with age.

Based on these parameters, the following values are calculated:

- Probability of receiving an initial exam as part of usual eye care for those without amblyopia (UsualAge)
- Probability of receiving an initial exam as part of usual eye care for those with amblyopia (Usual_AmbAge)
- Cumulative probability of receiving an exam under usual eye care for those without amblyopia (Cum_UsualAge)
- Cumulative probability of receiving an exam under usual eye care for those with amblyopia (Cum_Usual_AmblyopiaAge)
- Probability of a false positive diagnosis of amblyopia as part of a usual eye care exam (False_Usual_Age)
- Probability of amblyopia being detected as part of usual eye care (Detect_Usual_Age)
- Probability of following up with a referral if amblyopia is diagnosed (Follow_Usual_Age)
- Probability of complying with follow-up care (Treat_Usual_Age)
- Probability of successful treatment for amblyopia (Cure_Usual_Age)
- Probability that child has not previously been treated for amblyopia. (Untreated)

\[\text{Usual}_{\text{Age}} = \text{Usual}_{\text{rate}} \times (1 - \text{Cum}_{\text{Usual}_{\text{Age}}})\]

\[\text{Cum}_{\text{Usual}_{\text{Age}}} = \sum_{\text{age}=4}^{10} \text{Usual}_{\text{Age}}\]

\[\text{Usual}_{\text{Amb}}_{\text{Age}} = \text{Amb}_{\text{Like}} \times \text{Usual}_{\text{rate}} \times (1 - \text{Cum}_{\text{Usual}_{\text{Amb}}_{\text{Age}}})\]

\[\text{Cum}_{\text{Usual}_{\text{Amb}}_{\text{Age}}} = \sum_{\text{age}=4}^{10} \text{Usual}_{\text{Amb}}_{\text{Age}}\]

\[\text{Detect}_{\text{Usual}_{\text{Age}}} = \text{Untreated}, \times \text{Sensitivity}_{\text{Exam}} \times \text{Usual}_{\text{Age}}\]

\[\text{False}_{\text{Usual}_{\text{Age}}} = \text{Usual}_{\text{Age}} \times \text{Prevalence} \times (1 - \text{Specificity}_{\text{Exam}})\]

\[\text{Follow}_{\text{Usual}_{\text{Age}}} = \text{Detect}_{\text{Usual}_{\text{Age}}} \times \text{Refferal}_{\text{Exam}}\]

\[\text{Treat}_{\text{Usual}_{\text{Age}}} = \text{Follow}_{\text{Usual}_{\text{Age}}} \times \text{Adherence}_{\text{Exam}}\]

\[\text{Cure}_{\text{Usual}_{\text{Age}}} = \text{Treat}_{\text{Usual}_{\text{Age}}} \times \text{Effectiveness}_{\text{Age}}\]

\[\text{Untreated}_{\text{,}} = \text{Prev} - \sum_{\text{t}=1}^{\text{t}} \text{Treat}_{\text{Usual}_{\text{Age}}}\]

Patterns of usual eye care for those with a comprehensive exam or vision screening in the initial period

In subsequent periods, patterns of usual eye care for those with a preschool comprehensive exam or vision screening are assumed to the same as for those who did not participate in a preschool exam or screening program. The only difference is that the prevalence of amblyopia is lower in subsequent periods for those with an initial exam or screening, due to cases of amblyopia that are detected and successfully treated.

\[\text{Detect}_{\text{Usual}_{\text{Exam, Age}}} = \text{Untreat}_{\text{Exam}} \times \text{Sensitivity}_{\text{Exam}} \times \text{Usual}_{\text{Age}}\]

\[\text{False}_{\text{Usual}_{\text{Exam, Age}}} = \text{Usual}_{\text{Age}} \times \text{Untreat}_{\text{Exam}} \times (1 - \text{Specificity}_{\text{Exam}})\]
\[ 12a \] Detect_{\text{usual}, \text{screen}, \text{age}} = \text{Untreat}_{\text{screen}} \times \text{Sensitivity}_{\text{exam}} \times \text{Usual}_{\text{age}} \\

\[ 12b \] False_{\text{usual}, \text{screen}, \text{age}} = \text{Usual}_{\text{age}} \times \text{Untreat}_{\text{screen}} \times (1 - \text{Specificity}_{\text{exam}}) \]
References


19 Vision in Preschoolers Study (VIP Study) (http://www.nei.nih.gov/nei/trials/static/study85.htm).


20 Donahue SP, Johnson TM, Leonard-Martin TC. Screening for amblyogenic factors using a volunteer lay network and the MTI photoscreener. Initial results from 15,000 preschool children in a statewide effort. *Ophthalmology*. 2000 Sep; 107(9): 1637-44.


76 Hymers JM, Baker JD, Galang CM. The Effect of Amblyopia on Career Choices, presented at the 2001 AAPOS Meeting.


83 Van Leeuwen R. Eijkemans MJC Vingerling JR et al. Amblyopia in the Rotterdam Study; What can we learn from persons 55 years and older? Presentation at the 1st Rotterdam Amblyopia Meeting, November 2003.


90 Donahue SP. How often are spectacles prescribed to “normal” preschool children. Journal of AAPOS. 2004 (Jun); 8(3): 224-229.


