INTRODUCTION

The Acuity Card Procedure (ACP) is the gold standard for infant vision assessment. It is based on the tendency of infants and young children to exhibit a preference for viewing high-contrast gratings compared to a uniform luminance-matched gray field (Figure 1A) and incorporates reinforcement from a tester who maintains the child’s attention. The development of the ACP and the commercial availability of printed testing stimuli (Teller Acuity Cards [TAC]; Vistech Consultants, Inc., Dayton, OH, and TACII; Stereo Optical, Inc., Chicago, IL) have been instrumental in the assessment of infant vision.

Purpose: To determine if testing binocular visual acuity in infants and toddlers using the Acuity Card Procedure (ACP) with electronic gratings yields clinically useful data.

Methods: Participants were infants and toddlers ages 5 to 36.7 months referred by pediatricians due to failed automated vision screening. The ACP was used to test binocular gratings. Stimuli were presented on the Dobson Card. The Dobson Card consists of a handheld matte-black plexiglass frame with two flush-mounted tablet computers and is similar in size and form to commercially available printed grating acuity testing stimuli (Teller Acuity Cards II; Stereo Optical, Inc., Chicago, IL). On each trial, one tablet displayed a square-wave grating and the other displayed a luminance-matched uniform gray patch. Stimuli were roughly equivalent to the stimuli available in the printed TACII stimuli. After acuity testing, each child received a cycloplegic eye examination. Based on cycloplegic retinoscopy, patients were categorized as having high or low refractive error per American Association for Pediatric Ophthalmology and Strabismus vision screening referral criteria. Mean acuities for high and low refractive error groups were compared using analysis of covariance, controlling for age.

Results: Mean visual acuity was significantly poorer in children with high refractive error than those with low refractive error ($P = .015$).

Conclusions: Electronic stimuli presented using the ACP can yield clinically useful measurements of grating acuity in infants and toddlers. Further research is needed to determine the optimal conditions and procedures for obtaining accurate and clinically useful automated measurements of visual acuity in infants and toddlers.

has allowed for quantitative measurements of normal visual development\textsuperscript{2–5} and the evaluation of the effectiveness of treatments on visual outcome in infants and toddlers.\textsuperscript{6–8} However, highly trained and experienced testers are often necessary to obtain reliable measurements, and the printed stimuli are expensive to manufacture. These factors have limited the widespread use of the procedure in the clinic and research.

Several research groups are developing new methods of assessing visual acuity in infants and toddlers.\textsuperscript{9,10} These efforts are likely due to the need for a more automated method of acuity testing and technological advances that increase the feasibility of such a method. High-resolution digital displays and gaze tracking systems are now available and are becoming increasingly affordable. The utility of these systems for detecting clinically useful information has not yet been explored because initial studies included only children with no known visual, medical, or developmental impairments.

We assessed the utility of an electronic “acuity card,” called the Dobson Card in honor of our colleague, Velma Dobson, PhD, who greatly advanced our knowledge of visual development and who collaborated on the original development of the ACP TAC, and Dobson Card. The Dobson Card offers several advantages over the TAC/TACII: only one “card” is needed because spatial frequency can be varied electronically, luminance is constant across testing environments, and it allows for the possibility of easily generating and testing different types of stimuli.

\section*{PATIENTS AND METHODS}

\subsection*{Patients}

Patients were infants and toddlers with ages ranging from 5 to 36.7 months (based on gestational age) who failed instrument-based vision screening at a visit to their pediatrician. A parent/guardian provided written informed consent. This research complied with the tenets of the Declaration of Helsinki and was approved by the University of Arizona Institutional Review Board.

\subsection*{Apparatus}

The Dobson Card is a handheld matte-black plexiglass frame with dimensions equal to the TAC/TACII (25.5 × 55.5 cm). Two Google Nexus-7 (N7; Google Inc., Mountain View, CA) tablet computers are flush-mounted into the frame (Figures 1B-1C). Each N7 has a 17.83 cm display (1,920 × 1,200 pixels, 0.078 mm/pixel). During each trial, one N7 displays a square-wave grating and the other N7 displays a uniform gray patch that is luminance-matched to the gratings. Stimuli were roughly equivalent (due to pixel size limits) to the stimuli on the printed TAC/TACII (16 cards, ½ octave steps). To calibrate luminance for the two displays, an observer adjusted the gray patches on each N7 until the perceived luminance matched. To match the gratings to the gray patch, the observer increased viewing distance until the gratings could not be resolved and then matched the perceived luminance of the gratings to the gray patch on the other N7. Luminance for the grating and gray patch was 92 lux (Dr. Meter LX1330B light meter; Hisgadget, Union City, CA).

\subsection*{Procedure}

An experienced tester conducted standard ACP testing\textsuperscript{1} using the Dobson Card stimuli. The Dobson Card was presented in a TAC stage (Vistech Consultants, Inc., Dayton, OH) at a distance of 55 cm with lights dimmed to lessen distractions and eliminate reflections on the Dobson Card. An assistant controlled the Dobson Card displays via a Bluetooth keypad in response to the tester's verbal

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Figure1.png}
\caption{(A) Teller Acuity Card (TACII) (Vistech Consultants, Inc., Dayton, OH) and the (B) front and (C) back of the Dobson Card.}
\end{figure}
instructions to advance to higher or return to lower
spatial frequencies, allowing the tester to remain
masked to the location of the grating. The highest spatial frequency to which the child reliably re-
sponded was recorded as the child’s grating acuity.

Each child received a complete eye examina-
tion including cycloplegic retinoscopy conducted
30 minutes after the administration of one drop of
proparacaine 0.5% followed by one drop of cyclo-
pentolate 0.5%.

Data Analysis

Children were stratified into two groups based
on their cycloplegic retinoscopy: high refractive error
(meeting the American Association for Pediatric Oph-
thalmology and Strabismus [AAPOS] vision screening
referral criteria) and low refractive error (not meet-
ing AAPOS criteria). For children 30 months and
younger we used the 12 to 30 months age group cri-
teria (astigmatism 2.00 diopters [D], hyperopia 4.50
D, anisometropia 2.50 D) and for children 31 months
and older we used the 31 to 48 months age group cri-
teria (astigmatism 2.00 D, hyperopia 4.00 D, aniso-
metropia 2.00 D). Analysis of covariance compared
mean log transformed acuity scores (log cpd) for low
and high refractive error groups, controlling for age.

RESULTS

The final sample included 36 patients (50% female, age range: 5 to 36.7 months). All patients
completed testing. Of the 36 children, 14 had high
refractive error: astigmatism (10), astigmatism and
myopia (1), astigmatism and hyperopia (1), and hy-
peropia (2). Mean acuity was significantly poorer in
children with high refractive error compared to chil-
dren with low refractive error ($P = .015$). The effect
of age approached significance ($P = .055$). Figure
2 plots data from the high and low refractive error
groups with published normative data.\textsuperscript{2,3}

DISCUSSION

This study demonstrates that the Dobson Card,
an electronic stimulus similar in form to the printed
TAC/TACII stimuli, can differentiate between infants
and toddlers with minimal refractive error and those
with refractive errors requiring further evaluation.
This suggests that it can be used to obtain a clinically
useful test of infant and toddler visual acuity.

Dobson Card measurements were generally
lower than acuity measured with the TAC and TA-
CII (Figure 2). However, the norms are also dif-
f erent for the two versions of printed cards (TACII
scores < TAC scores). Contrast and luminance
differences may have contributed to the lower scores
obtained with the Dobson Card. In addition, due
to design differences, the child’s task with the TAC/
TACII differs from the task with the Dobson Card.
For the TAC/TACII, the child must detect a single
grating in a uniform gray field (Figure 1A). For the
Dobson Card, the child must compare two stimuli
and detect the grating (Figure 1B). The compari-
son task may be more difficult, affecting the child’s
willingness to participate long enough to achieve a
true threshold acuity, and may also alter the child’s
looking behavior. After a brief initial look (which
may sometimes be missed by the tester), children
tended to look back and forth between the two tab-
let displays. Further research will assess the effect of
the type of task (detection versus comparison) on
thresholds and alternatives for monitoring patient
gaze (eg, viewing the child on a video monitor, rath-
er than through the Dobson Card).

The prototype used in the current study was
designed to be similar in form to the TAC/TACII
to allow us to assess the utility of computerized dis-
plays while controlling for other variables by using
the well-validated ACP. Further research will focus
on developing a method that relies less on the tes-
ter’s training and experience, while still engaging
the child. When stimuli approach a child’s acuity

\textbf{Figure 2.} Grating acuity (log cpd) by corrected age (months) for
children with significant refractive error (filled symbols) and for
children without significant refractive error (open symbols). Refer-
ence lines are upper and lower tolerance limits for 90% of the
population with 95% probability calculated from Teller Acuity
Card\textsuperscript{2} (dashed lines) and Teller Acuity Card II\textsuperscript{3} (solid lines) norma-
tive binocular acuity data.
threshold, the child often becomes easily distracted. In addition, children with visual, neurological, or developmental deficits may become distracted or uncooperative more quickly than normally developing children. A key, and perhaps a critical, component of the ACP is inclusion of a tester who maintains the child’s attention. Additional research will determine whether computer stimuli (eg, animations) can effectively engage attention from infants to preschoolers and across a range of developmental abilities. Further research will also focus on use of an automated method of gaze assessment and analysis that, if effective, will offer a more objective method of assessing the child’s behavior, reduce reliance on tester training and experience, and make acuity testing more feasible for widespread use in the clinic and in research.

REFERENCES