New Mobile Technologies and Visual Acuity

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***Abstract*-Mobile devices have shown promise in visual assessment. Traditional acuity measurement involves retro-illuminated charts or card-based modalities. Mobile platforms bring potential to improve on both portability and objectivity. The present research activity relates to design and validation of a novel tablet-based infant acuity test. Early results in an adult cohort, with various levels of artificially degraded vision, suggest improved test-retest reliability compared with current standards for infant acuity.**

Future pragmatic trials will assess the value of this emerging technology in pediatric visual screening.

I. Introduction

It is estimated that in almost half of the children who are blind today, the underlying cause could have been prevented, or the eye condition treated to preserve vision or restore sight [1].

Early treatment of poor vision in a child is of vital importance, as uncorrected poor vision in one or both eyes precludes the normal development of the visual brain, resulting in amblyopia. Uncorrected visual problems become permanent if not addressed in early childhood. A significant portion of paediatric blindness is preventable by non-surgical means, including simple spectacle correction and timely patching techniques.

The crucial first step is detection. It is widely accepted that preschool vision screening can help in the early detection of reduced visual acuity. Currently, it is estimated that six out of every 10,000 children born in the UK every year become severely visually impaired (corrected acuity worse than 6/60 or 1.1 logMAR) by the age of 16 years. The most common cause is amblyopia, which affects approximately 3% of the UK child population. The Royal College of Ophthalmologists guidelines state that 'a visual assessment by an orthoptist should be carried out on all children between the ages of four and five years.' This screening is aimed at 'detecting unsuspected visual impairment in one or both eyes. Children who achieve less than 0.2 LogMAR (6/9.5 Snellen) in either eye, despite good co-operation should be referred.' However, it has been reported that there is a deficiency in vision screening specialists, falling short of such a stipulation, as investigated by Consumer company Which? (2011) [2]. It was found that 1 in 5 primary care trusts in England were providing inadequate levels of visual screening for pre-school children between the ages of four and five years.

A recent convergence of technologies combine high-resolution touchscreen devices with advanced computing power, and connectivity to an electronic patient record, bringing potential to improve upon existing standards with low-cost portable solutions. Paradoxically, owing to the mass production and competitive pricing of leading mobile devices, the cost of a computer tablet is significantly lower than current card-based standardised infant acuity tests.

The touchscreen high-resolution display brings the potential for a robust vision test in the form of a computer game for children. A programmed stair-casing paradigm with automatic reporting could reduce the necessity for trained specialists to conduct testing, and consequently extend the reach of visual screening programs with the ubiquitous online app markets.

In this paper, we outline our novel paediatric acuity test design, and report our interim results in a preliminary adult cohort, comparing a novel paediatric acuity game with traditional standards.

II. Aims

A. *Produce an infant acuity test for the Apple iPad 3 (Apple inc, Cupertino, California, USA)*

i) Create a digital acuity game for pre-verbal children, which will offer preferential-looking functionality for infants and patients with special needs, lacking speech and coordinated movement.

ii) Allow functionality for older children, enabling independent by virtue of a touchscreen game format, without requirement of direct instruction by a specialist

B. *Compare the tablet-based test, Peekaboo Digital Acuity (PDA), with current clinical standards in an adult cohort.*

While the acuity test, provisionally called "*Peekaboo*", is ultimately aimed at infants, testing in an adult cohort allows collection of preliminary data from a reliable population, less prone to loss of concentration when subject to multiple vision tests. Moreover, testing adults permits a more expansive range of acuities by artificially degrading vision (blurring spherical lenses), which would not be tolerated in an infant trial.

The adult cohort allows an opportunity to refine the testing model, and provide a measure of reliability in advance of testing young children as part of a pragmatic trial, evaluating diagnostic accuracy in primary care and pre-school screening.

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III. METHODOLOGY

A. Digital Test Design

All graphical elements were designed and scaled using Adobe Photoshop Creative Cloud (Adobe Systems inc, San Hose, California, USA). The acuity test application was designed in HTML5, to the screen specification of the 3rd Generation iPad with Retina Display, comprising a 9.7‐inch (diagonal) LED‐backlit multi‐touch display with In-Plane Switching (IPS) technology. The screen resolution measured 2048-by-1536 pixels, at 264 pixels per inch (ppi).

High-frequency grating black-and-white visual targets were chosen as the optotype model. This method has well described [3], and remains the clinical standard for infants in card-based preferential-looking tests, such as the Keeler Acuity Test (KAT, Keeler ltd, Winsor, United Kingdom), against which PDA was compared in the present study.

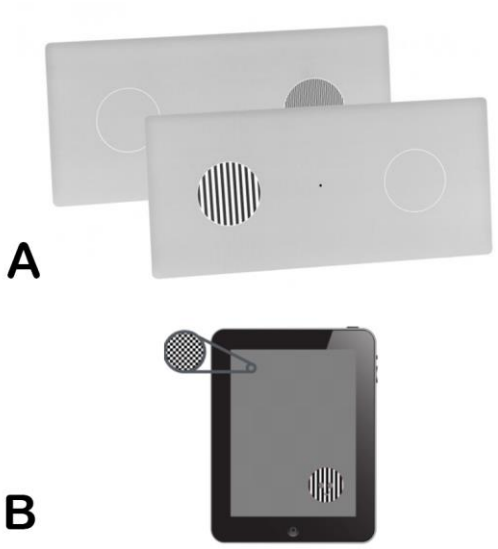

Figure 1. A: The Keeler Acuity Test. B: The Peekaboo Digital Acuity Test

The ideal test involves an engaging target that directs and holds the child's attention. In contrast to the traditional circular/square optotype targets, the digital high contrast grating targets were constructed as simple smiley-face graphics (Figure 1B). This format was chosen as faces have been demonstrated as salient to recognition in young infants, with newborns being attracted to faces from hours after birth [4]. It has been proposed that face recognition represents a special stimulus category, processed differently from other stimuli [5].

To achieve a consistent and equal average luminance of the optotype target and background, in departure from card-based techniques that employ a homogenous grey, the background comprises an alternating black/white checkerboard pattern at the maximum resolution permitted by the device display (Figure 1B). To the observer, this appears as a uniform grey.

The digital test was designed as a basic computer game, to be performed at 38cm, matching the test distance recommended for KAT. At this distance, the screen resolution is sufficient to assess grating acuities from -0.1 to 2.3 logMAR (equivalent to near blindness).

The design is such that the individual being tested is encouraged to tap or point to the smiling face graphic, following a demonstration by the tester with a low-frequency optotype example. The optotypes are positioned consistently at 1 of 4 corners of the screen in a pseudo-random order. To prevent cues from the tester, the device is held facing the child in a position such that the tester is masked to the screen. For infants too young to point or press, an alternative technique is employed, whereby the tester infers which screen-corner the child is looking, by observation of the child's eye-movements. The tester presses the relevant quarter of the screen with the fingertips overlapping the edge of the device (Figure 2). If there are no meaningfully directed eye movements, the presented level of acuity is assumed to be below the level of detection, and lower-frequency target is presented. A sound and animation reward is played if the position is correct. This sound alert includes a voice descriptor signposting the level of acuity attained, informing the tester without the need to rotate the device to assess where the graphic has appeared. This technique prevents disruption of the test sequence, and helps maintain a consistent working distance by limiting movement of the device.

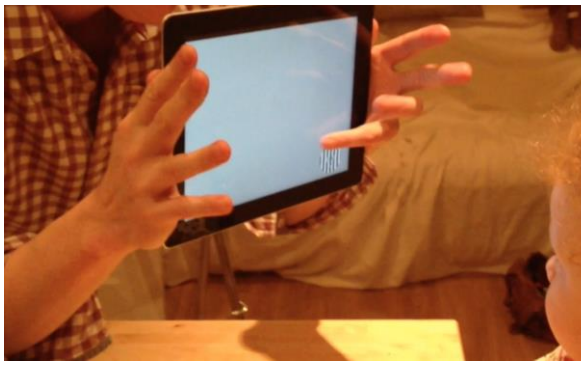

Figure 2. Peekaboo Digital Acuity Test in use as preferential-looking test

B. Clinical Testing

Volunteers were recruited from departmental staff from Gartnavel General Hospital, Glasgow. All volunteers underwent reduced Snellen acuity testing (Sheridan Gardiners Near Acuity, Keeler ltd, Windsor, United Kingdom) performed at 33cm, with habitual correction if required. Eyes with near acuity poorer than 6/9 were excluded. The adult group (N=10, 20 eyes), underwent each acuity test monocularly with usual correction, if worn, plus 3 spherical blur conditions (+16, +8, +4 dioptre), which were placed over the habitual near correction if required. This allowed a total of 80 tests across a wide range of acuities (-0.1 to 1.8 logMAR). All acuity scores were converted to logMAR for the purposes of statistical analysis.

For all blur conditions, 5 minutes of blur-adaptation was provided prior to commencing testing. Acuity was measured

with 3 tests: Reduced Snellen (33cm), KAT (38cm), and PDA (38cm). The order of testing was randomised and equally balanced. To assess reliability, all tests were repeated 24-72 hours later.

For the PDA, autobrightness was deactivated, and the brightness set to 50%. In accordance with findings relating to iPad screen stability [5], the device was switched on, and display left to stabilise for 15 minutes prior to commencing clinical testing. For both the KAT and PDA, grating acuity was presented twice at each level, starting with lowest frequency gratings. Testing continued in 0.1 logMAR steps until an error was made. A forced-choice preference assessment model was adopted. AL (senior orthoptist) or IL (ophthalmologist) performed testing. The same tester performed test/retest for a given volunteer.

The variability of collected data was explored to assess reliability via Bland Altman analysis. For test-retest results, the inter-test differences were normally distributed.

IV. Results

High-contrast frequency patterns were presented at an equal distance in both test modalities. Theoretically, the matched line-widths subtend equivalent angles at the retina to provide equivalent results. However, results differed significantly between the card-based KAT and tablet-based PDA groups ($p<0.001$, paired t test). Despite this, Bland Altman analysis comparing KAT with PDA results (Figure 3) reveals the mean difference in acuity results between the two tests is less than one logMAR level (-0.07). On comparison of test-retest data, figures 4 and 5 illustrate superior reliability of PDA, with 95% of the measured inter-test differences falling within 0.3 logMAR for DCA, compared with >0.4 logMAR difference with KAT. In each difference plot, there is an even spread of detected differences, without weighting towards better or poorer acuities

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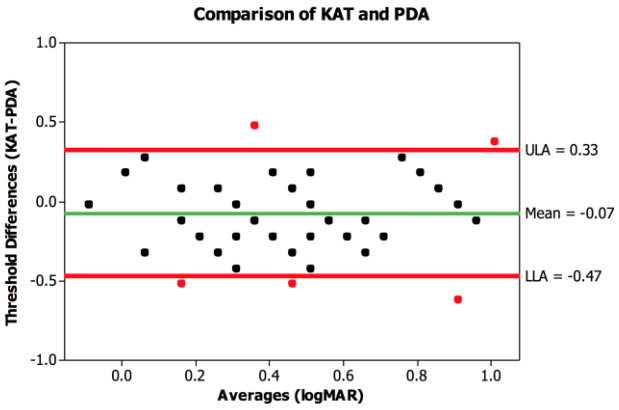

Figure 3. Bland Altman Plot demonstrating difference between the Keeler Acuity Test and Peekaboo Digital Acuity versus the mean acuity threshold.

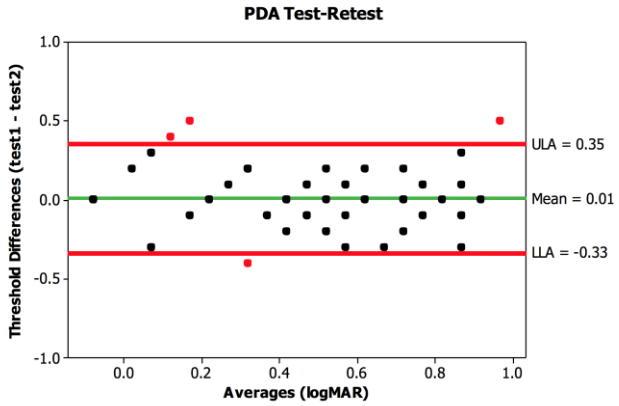

Figure 4. Bland Altman Plot demonstrating the difference between Test 1 and Test 2 (Retest) for the Peekaboo Digital Acuity, versus the mean acuity threshold. The limits of agreement fall within approximately 1 octave.

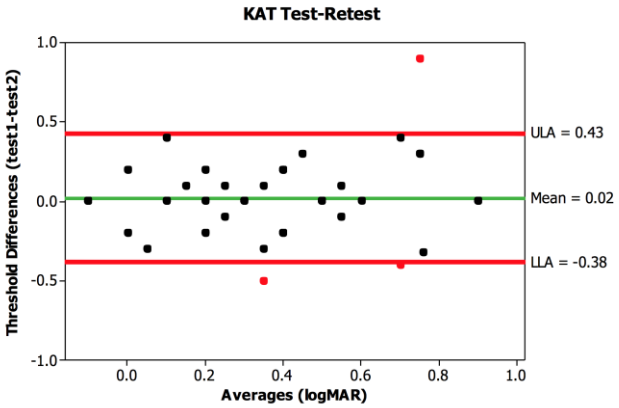

Figure 5. Bland Altman Plot demonstrating the difference between Test 1 and Test 2 (Retest) for the Keeler Acuity Test, versus the mean acuity threshold. The limits of agreement are greater than that of Digital Acuity.

V. Discussion

Despite similarly sized high-frequency targets being presented in both digital and card-based tests at any given level, the acuity results obtained with each test are significantly different ($p=0.001$). However, the mean difference in acuity results between KAT and PDA was approximate to a difference of less than one logMAR *line*. However, despite this small difference in average acuities, the tablet-based test demonstrated *improved* test-retest performance on Bland Altman analysis when compared to the traditional KAT, suggesting superior *reliability* in this preliminary cohort when testing was performed with the iPad 3 test.

The significant differences in absolute acuities likely to relates to the fundamental differences in physical characteristics of the device screen compared to card, namely the differences in contrast between black and white elements in a card-based format versus the lambertian surface of the tablet screen.

Other significant differences relate to differnces in test design: a) the construction of the optotypes in each test (face optotpype in PDA, compared to uniform circular optotypes in

KAT), b) contour interaction borders (present in KAT, but absent in PDA), and c) differences in the composite background pattern between the two modalities to achieve an equal average luminance to the foreground optotypes.

While there are obvious advantages to using a computer tablet to measure vision, important limitations include reflections and glare from the glossy surface.

Aslam et al investigated the fundamental physical characteristics of the iPad 3 display in relation to vision testing. Their results suggested that while the tablet screen was unable to exactly match the low levels of contrast in the Pelli-Robson contrast sensitivity chart [6], the device has the potential to screen for contrast sensitivity defects across a broad range. Furthermore, while a reduction in luminance was found towards the corners of the screen, the impact on contrast of the targets was minimal, typically around only 1%. Investigation of the impact of viewing angle similarly found that despite relatively high absolute changes in luminance, contrast remained highly stable, suggesting minimal significant impact on clinical testing.

Black et al [7] evaluated the first generation iPad (Apple inc.) against traditional measures for adult distance acuity (externally illuminated and computerized letter charts), reporting that the glossy screen of the iPad (Apple inc) was susceptible to glare, resulting in acuity measurements approximately 2 lines poorer than those made with the iPad fitted with an antiglare screen (Sentry Anti-Glare Screen Protector, Enki, Atlanta, Georgia, USA), and positioning the device away from sources creating reflected (veiling) glare. With such glare-reduction measures instituted, the iPad measures were equivalent to those made with the gold standard charts. One limitation of this study relates to the "anti-glare" group involved not only use of the anti-glare screen, but also "strategies to reduce glare" that included "positioning perpendicular to the floor so no sources of glare were visible by reflection". It is not clear whether such attention to positioning could negate the need for the anti-glare screens. The need for such measures to enhance the efficacy of tablet-based vision testing remains a subject for future study. No such glare-filters were employed in the present study.

Future trials involving infants are indicated to definitively assess the value of the new technology, and to address important questions relating to engagement with the test, time-to-test, and performance in the hands of a non-specialist.

Automation of stair-casing, objectivity of child-led screen tapping, and the capacity to introduce a game-based format with animation/sound rewards, all combine to make a digital tablet test an attractive alternative to conventional card-based techniques. Furthermore, the markedly reduced size of a computer-tablet compared to large sets of cards make the digital option a far more portable option.

Furthermore, recent technological advances pertinent to vision testing include the recent advent low-cost of commercial eye-trackers, which are now compatible with tablet devices, lending the potential to integrate such emerging technology to further enhance objectivity of acuity testing. Potential software enhancements also bring the capacity to automatically detect the eye-to-target distance, negating the dependency on maintaining a fixed working distance. Such a development could allow a *dynamic* acuity test, less vulnerable to the confounding effect of children naturally moving towards the target. By leveraging the technology of leading mobile devices, many of the challenges in clinical testing can be mitigated, making testing easier, faster and less dependent on the tester experience.

If found to be a credible alternative to current clinical standards, app-based acuity tests could prove a disruptive technology in the field of infant vision testing, with potential impact in low- and middle-income settings.

However, conclusions drawn from the performance of the novel technology when tested on adults cannot be assumed to be true for an infant population, given the inherent differences in ability to comply with instruction, concentrate on the visual task, and inherent differences in the developing visual system. Nevertheless, the results from this preliminary study are promising, and support the next step of testing an infant cohort, and collecting normative data across a range of age-groups. Translational research is required to evaluate the potential impact of the technology on visual screening.

CONCLUSION

With intelligence within software, and sophistication of leading tablet displays, it is possible that poor vision can be detected objectively with a digital solution, without the need of subspecialist orthoptist-led screening programs. This brings a potential answer to the unmet need in pre-school screening, where non-specialists, such as a domiciliary health visitor or school nurses, can potentially perform visual screening in a more cost-effective fashion.

In advance of a pragmatic trial within primary care, head-to-head studies are required to evaluate the role of evolving technology in comparison with traditional standards.

REFERENCES

[1] C. Gilbert, A Foster. "Childhood blindness in the context of VISION 2020". *The Right to Sight. Bulletin of the World Health Organization,* 2001, 79 (3)

[2] Retrieved from: http://www.which.co.uk/news/2011/04/kids-eyesight-at-risk-from-poor-screening-251738/ (accessed 10/04/2013)

[3] V Dobson, M McDonald and D. Y. Teller, "Visual acuity of infants and young children: torced-choice preferential looking procedure," *Am Orthopt J.,* vol 35, 1985, pp. 118-25

[4] C.C. Goren, M. Sarty, and P.Y.K. Wu, "Visual following and pattern discrimination of face-like stimuli by newborn infants," *Pediatrics,* vol. 56. 1975, pp. 44–549

[5] J. W. Tanaka, and M. J. Farah. "Parts and wholes in face recognition". *Quarterly Journal of Experimental Psychology,* vol. 46A, pp. 225–245, 1993

[6] T. M. Aslam, I. J. Murray, M. Y. Lai, E. Linton, H. J. Tahir, and N. R. Parry, "An assessment of a modern touch-screen tablet computer with reference to core physical characteristics necessary for clinical vision testing". *Interface.* Vol. 10(84), pp. 20130239, 2013

[7] J. M. Black, R. J. Jacobs, G. Phillips, L. Chen, E. Tan, A. Tran, B. Thompson. An assessment of the iPad as a testing platform for distance visual acuity in adults. *BMJ Open*. 10.1136, 2013