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Crowding and visual acuity measured in adults using paediatric test letters, pictures and symbols

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A B S T R A C T

Crowding refers to the degradation of visual acuity for target optotypes with, versus without, surrounding features. Crowding is important clinically, however the effect of target-flanker spacing on acuity for symbols and pictures, compared to letters, has not been investigated. Five adults with corrected-to-normal vision had visual acuity measured for modified single target versions of Kay Pictures, Lea Symbols, HOTV and Cambridge Crowding Cards, tests. Single optotypes were presented in isolation and with surrounding features placed 0–5 stroke-widths away. Visual acuity measured with Kay Picture optotypes is 0.13–0.19 logMAR better than for other test optotypes and varies significantly across picture. The magnitude of crowding is strongest when the surrounding features abut, or are placed 1 stroke-width away from the target optotype. The slope of the psychometric function is steeper in the region just beyond maximum crowding. Crowding is strongest and the psychometric function steepest, with the Cambridge Crowding Cards arrangement, than when any single optotype is surrounded by a box. Estimates of crowding extent are less variable across test when expressed in units of stroke-width, than optotype-width. Crowding for single target presentations of letters, symbols and pictures used in paediatric visual acuity tests can be maximised and made more sensitive to change in visual acuity, by careful selection of optotype, by surrounding the target with similar flankers, and by using a closer target-flanker separation than half an optotype-width.

1. Introduction

Visual acuity is routinely measured by clinicians as part of ocular health and visual function assessment, and during pre-school vision screenings. Detection of amblyopia, a developmental vision disorder affecting approximately 3.5% of adults (Attebo et al., 1998), is a key reason for pre-school vision screening (Bodack, Chung, & Krumholtz, 2010; Friendly, 1978; Kemper, Keating, Jackson, & Levin, 2005; Schlenker, Christakis, & Braga-Mele, 2010; Schmucker et al., 2009; U.S. Preventive Services Task Force, 2004) as treatment is more likely to be successful if initiated early in life (Flynn, Schiffman, Feuer, & Corona, 1998; Flynn et al., 1999). Inter-ocular visual acuity differences are a key component of amblyopia diagnosis and monitoring of treatment outcomes (Attebo et al., 1998; Flom & Neumaier, 1966; Flynn et al., 1998, 1999; Holmes & Clarke, 2006; Simons, 2005). A number of visual acuity tests are available for the testing of pre-literate children, as well as in adults who cannot communicate using the Latin alphabet. These tests vary in the optotypes chosen, i.e., letters, symbols or pictures, their arrangement on the test chart, i.e., a single optotype, a line of optotypes, or the presence of other features around the target optotype such as other letters, bars or a box (Anstice & Thompson, 2014; Fern & Manny, 1986). There are also differences in the discriminability of optotypes used in these charts (Candy, Mishoulam, Nosofsky, & Dobson, 2011).

Visual acuity for a target optotype measured with surrounding features is worse than that measured when isolated (Flom, Weymouth, & Kahneman, 1963; Formankiewicz & Waugh, 2013; Jacobs, 1979; Leat, Li, & Epp, 1999). This negative spatial interaction effect on target resolvability is generally referred to as "crowding" and may be greater in amblyopes than in individuals with normal vision (Hess, Dakin, Tewfik, & Brown, 2001; Levi, Hariharan, & Klein, 2002; Mayer & Gross, 1990; Morad, Werker, & Nemet, 1999; but see Flom, Weymouth, & Kahneman, 1963; Stuart & Burian, 1962). Contour interaction was proposed to be a sub-component of crowding (along with attention and eye movements) by Flom et al. (1963) and refers to the detrimental effects of bars (or contours) that surround the target. In crowding, detrimental effects are produced by surrounding the target with more complex features similar to the target itself, such as other letters. Alternatively, contour interaction and crowding have been

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proposed to be distinct entities (Pelli, Palomares, & Majaj, 2004). However clinically, contours, boxes, and neighbouring optotypes have been incorporated into visual acuity charts to introduce "crowding" effects (Atkinson, Anker, Evans, Hall, & Pimm-Smith, 1988; McGraw & Winn, 1993; McGraw, Winn, Gray, & Elliot, 2000; Schlenker et al., 2010; Simmers, Gray, & Spowart, 1997) to improve the sensitivity of visual acuity measurement in detecting amblyopia.

The position of crowding features on commercially available acuity charts is based primarily on the findings of Flom et al. (1963). Flom et al. investigated contour interaction using an orientation discrimination task with a rotated C flanked by bars. They reported that performance is maximally degraded when bars are placed at an edge-to-edge distance of 0.4 letter (or 2 stroke) widths. Crowding features, such as other letters, bars or a box, on children's visual acuity charts are generally placed 0.5 optotype-widths away from the target letter or line of symbols, pictures or letters (Atkinson et al., 1988; Holmes, Beck, Repka, et al., 2001; Jones, Westall, Averbeck, & Abdolell, 2003; McGraw & Winn, 1993; Vision in Preschoolers Study Group, 2005). A separation of 1 optotype width has been used on the Sonksen chart (Salt, Wade, Proffitt, Heavens, & Sonksen, 2007), which follows the design of the Bailey–Lovie chart (Bailey & Lovie, 1976).

Acuity tests designed for young children (and adults who cannot communicate using the Latin alphabet) normally require recognition or matching of letter or picture/symbol optotypes, which are more complex than a Landolt C. Recent research has indicated that crowding for letter optotypes would be enhanced if crowding features were placed closer to the optotypes than in currently available charts (Formankiewicz & Waugh, 2013; Song, Levi, & Pelli, 2014). Crowded tests are recommended for children's vision screening programs (Cotter, Cyert, Miller, Quinn, & National Expert Panel to the National Center for Children's Vision and Eye Health, 2015; Solebo & Rahi, 2013); specifically isolated optotypes (HOTV or Lea) with crowding bars are considered "best-practice" for children less than 6 years of age (Cotter et al., 2015). The effects of varying the position of crowding features on visual acuity measured with single picture and symbol optotypes have not yet been investigated.

In the present study, crowding for single target presentations of optotypes from four visual acuity charts, i.e., Kay Pictures, Lea Symbols, HOTV and Cambridge Crowding Cards, is compared in adult observers. Kay Pictures (Kay, 1983) are commonly used in the UK and Europe (Anstice & Thompson, 2014; Beirne, McIlreavy, & Zlatkova, 2008; Little, Molloy, & Saunders, 2012; Shah, Laidlaw, Rashid, & Hysi, 2012; Williams et al., 2015) Each optotype-width (or height) contains 10 stroke-widths to enable the more intricate pictures to be recognizable by young children, whilst having the same stroke-width as Snellen letters (Kay, 1983). Lea Symbols, recently recommended by a National Expert Panel (USA) to be used for vision screening in young children (Cotter et al., 2015), have sizes scaled to provide visual acuities similar to the Landolt C and contain, on average, 7 stroke-widths per optotype in order to keep the total amount of blackness closely equal (http://www.lea-test.fi). HOTV optotypes follow the Snellen letter design and contain 5 stroke-widths per optotype (Snellen 1862 cited by Bennett, 1965; British Standards Institution., 2003; Sheridan & Gardiner, 1970); Cambridge Crowding Cards use HOTVX as target letters, and other Sheridan-Gardiner letters to surround the target letter (Atkinson et al., 1988; Sheridan & Gardiner, 1970). The position of crowding features in visual acuity tests is normally specified in terms of target optotype size (Holmes et al., 2001; Jones et al., 2003; McGraw & Winn, 1993), however visual acuity is based on the optotype detail, or stroke-width. In this study we examine whether optotype- or stroke-width provides a more consistent unit for specifying crowding position across picture, symbol and letter acuity tests.

The purpose of this study is therefore (1) to compare visual acuity measured using single target presentations of optotypes from different visual acuity tests, (2) to determine the optimum positioning of crowding features on single target presentations, and (3) to determine which units (optotype- or stroke-widths) are best for specifying the position of crowding features. Whilst it would be beneficial to investigate crowding for these optotypes in young children, with adult participants a range of flanker positions and target types can be tested using rigorous psychophysical methods. The results will have direct applicability to adults who cannot communicate using the Latin alphabet, and will also be helpful in selecting only a few conditions to be tested on young children. The implications of our results obtained with adult participants, for the testing of children, will also be discussed.

2. Method

2.1. Apparatus

The stimuli were generated using a custom-written Matlab program (MathWorks™) on a Dell Precision T3400 computer driving a Cambridge Research Systems ViSaGe (Visual Stimulus Generator), a system which has integrated support for gamma correction. The stimuli were displayed on a Mitsubishi Diamond Pro 2070^{SB} CRT computer monitor. The screen resolution was 1104×828 and the frame rate was 120 Hz. The CRT display was calibrated and gamma-corrected using an OptiCal photometer to correct each gun's non-linearity. The monitor was switched on at least 60 min before data collection began to ensure the luminance output was stable.

2.2. Stimuli

Optotypes used in this study were derived from four preliterate visual acuity charts: Kay Picture Test (Kay Pictures Ltd, Tring UK) (Kay, 1983), Lea Symbols (Good-Lite, Illionois, USA) (Hyvarinen, Nasanen, & Laurinen, 1980), HOTV (Precision Vision, Illionois, USA) (Lippmann, 1971) and Cambridge Crowding Cards (Clement Clarke, Harlow, UK) (Atkinson et al., 1988). Optotypes were scanned from the original charts, converted to matrices and scaled for the different sizes required. They were displayed as black images (0.6 cd/m^2) on a white background (102 cd/m^2), at a contrast of 99.4%.

The original charts comprise different numbers of optotypes. To equalise the guess rate (at 1 in 4) across tests, target optotypes had to be removed from the Cambridge Crowding Cards and Kay Picture Test as the Lea Symbols and HOTV charts use four optotypes. The Cambridge Crowding Cards use five target optotypes (H, O, T, V and X) as standard, four being the same as in the HOTV chart and so, for the purposes of this study, the X was not used. The Kay Picture Test has eight optotypes (apple, boot, clock, cup, duck, fish, house and truck) and so for the current study, a preliminary experiment was conducted to choose four pictures that gave equivalent visual acuities and crowding effects.

Optotypes were displayed individually without crowding features (referred to as the isolated condition), and with crowding features at a separation of 0 (abutting), 1, 2, 3, 4 and 5 stroke-widths away. Separation is defined as the distance between the optotype edge and the inner edge of the crowding feature(s). In the main experiment, for the Kay Pictures, Lea Symbols and HOTV tests, the crowding feature was a box, which surrounded a single target optotype (in commercially available charts, a box is placed around a group of 4 or 5 optotypes). For the Cambridge Crowding Cards, the single target optotype was surrounded by four letters (A, C, L