Benefits of low vision aids to reading accessibility

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Word count: 4755; 2 figures, 4 tables.

Declarations of interest: none.

Abstract

The Reading Accessibility Index (ACC) has been proposed as a single-value reading parameter that can capture information on both reading speed and print sizes that can be read. It is defined as the average reading speed across a relevant range of print sizes (1.3-0.4logMAR), normalised by typical young-adult reading speed of 200wpm, and with values typically in the range of 0-1. This study determines the impact of low vision aids (LVAs) on reading by evaluating ACC values for visually impaired observers reading both without and with an optical LVA. A secondary analysis of previously published data obtained from 100 visually impaired observers attending low vision assessments was undertaken. Observers had mixed causes of visual impairment but predominantly macular degeneration (n=55). All used an LVA for reading, with 88% using it 'often' or 'very often'. MNREAD reading parameters, including ACC, were determined both for reading without an LVA (clinical function) and with the LVA habitually used for reading (aided function). There was a significant (p<.001) improvement in ACC from clinical (0.31 (95% CI 0.25, 0.36)) to aided conditions (0.47 (0.41, 0.52)). Average improvement in ACC with an LVA was 0.16 (0.13, 0.18), but the benefits of LVAs in terms of improvement in ACC could not be predicted from clinical visual function. Even with an LVA reading accessibility is, on average, markedly reduced from normal levels. The ACC is a potentially valuable outcome measure for reading rehabilitation interventions.

Keywords:

Reading; Vision tests; Visual impairment; Low vision; Sensory aids; Rehabilitation

Abbreviations :

ACC   Reading Accessibility Index

LVA   Low vision aid

1. Introduction

Assistance with reading is a key rehabilitation need for people with visual impairment (Rubin, 2013). To determine the benefits of reading rehabilitation, appropriate outcome measures are needed. Reading speed is often used as an outcome measure (Virgili et al., 2018), since it is a good predictor of visual difficulty (Hazel, Petre, Armstrong, Benson, & Frost, 2000; McClure, Hart, Jackson, Stevenson, & Chakravarthy, 2000). The ability to read print of different sizes is also of practical importance (Legge and Bigelow, 2011), and measures of reading acuity (RA; the smallest size of print that can be read) and critical print size (CPS; the smallest size of print that can be read at maximum reading speed (MRS)) can indicate whether someone would be able to read print of a specific size.

A single measure of reading function that can indicate a person's reading ability, taking both speed and print size into account, would be potentially valuable as an outcome measure for reading. A 'Reading Index' (McClure et al., 2000) has been suggested, defined as reading speed divided by print size. This measure does take both speed and size into account, and relates well to perceived difficulty with activities of daily living when considered as the MRS divided by the CPS (Tabrett and Latham, 2011). However, derivation of the Reading Index in this way relies on accurate identification of the CPS, which can often be difficult when an observer is visually impaired (Rubin, 2013). Different methods of CPS calculation result in different values (Patel, Chen, da Cruz, Rubin, & Tufail, 2011), and variability in reading speed with print size in the low vision observer can mean that standard algorithms fail to identify an appropriate CPS (Calabrèse et al., 2018). A 'Reading Accessibility Index' (ACC) has recently been proposed (Calabrèse, Owsley, McGwin, & Legge, 2016), which is a single value representing an individual's mean reading speed across the 10 largest print sizes on the MNREAD Acuity Chart (1.3-0.4 logMAR at 40cm in angular terms, or 8-1 Sloan M in physical terms), normalised by 200wpm (the average reading speed for normally sighted young adults). ACC values therefore typically range between 0 (unable to read print of these sizes) and 1 (print of these sizes read at 200wpm), with values greater than 1 possible for faster readers. The potential benefits of the ACC include that it is a single-value measure that captures both an individual's range of accessible print (across sizes from that are typically found in newspaper headlines through to that in running text in books and newspapers (Legge and Bigelow, 2011)), and reading fluency within this range. The ACC is also a value that can be calculated without the need to calculate CPS by plotting results graphically or by curve fitting, and thus without some of the issues that arise when trying to identify CPS from variable or limited data obtained from people with vision loss.

Calabrèse et al (2016) suggest that ACC might be used to evaluate the effect of interventions in reading. Here, we present a retrospective analysis of previously published data (Tabrett and Latham, 2011; Latham and Tabrett, 2012) to evaluate the extent to which optical low vision aids (LVAs), the principal optical intervention used in reading rehabilitation for visually impaired people, impact on ACC.

2. Methods

2.1 Participants

Data from a previous study (Tabrett and Latham, 2011; Latham and Tabrett, 2012) were evaluated as a secondary analysis. The sample consisted of 100 people over the age of 18 years with visual impairment of at least 6 months duration which they felt had caused restriction in their daily life, and who were attending low vision assessments. Data were collected at Essex County Hospital, Clacton and District Hospital, and Anglia Ruskin University Eye Clinic between October 2008 and May

2010. Ethical approval was granted by Anglia Ruskin University and NHS Essex Research Ethics Committees, and the tenets of the Declaration of Helsinki were observed. Informed consent was obtained from all participants.

There were 100 participants (39 males, 61 females), of average age 78±13 years (range 25-98 years). The primary self-reported causes of vision loss were age-related macular degeneration (AMD; 55 people), glaucoma (9), diabetic retinopathy (8), optic neuritis (3) and corneal dystrophies (3). Nystagmus, cerebrovascular accident, retinitis pigmentosa, and macular pathologies other than AMD were reported by two people each, and retinopathy of prematurity, cataract, myopic degeneration, retinal detachment and presumed ocular histoplasmosis syndrome were reported by one person each. Nine people did not know the cause of their visual loss. For the purposes of sub-analyses, it was considered that 57 people had macular conditions (55 AMD, 2 other macular pathologies), and 43 had other conditions.

Participants were asked to bring LVAs that they used for reading to the assessment, and the type and power of the aid that the patient selected for reading was noted. Participants were asked how frequently they used LVAs on a 4 point Likert scale (seldom (one day a week or less), occasionally (up to 3 days a week), often (up to 4 days a week), or very often (daily)). The LVAs selected for use in the aided reading task and their reported frequency of use are outlined in Figure 1. All observers used an LVA for reading, with 88% using it 'often' or 'very often'. The mean dioptric power of illuminated hand magnifiers used was +22±12D (range +8 to +56D), for illuminated stand magnifiers was +24±13D (range +8 to +56D), and for non-illuminated hand magnifiers was +10±5D (range +5 to +20D). The category of 'relative distance magnification' included those wearing 'high add' (≥+4D) reading spectacles, myopes removing their glasses to read at a closer working distance, and younger patients using a close working distance and accommodation. The 'other' category included individual instances of use of a torch, task lighting, needlework, dome, and bar magnifiers, and a spectacle mounted telescope.

Figure 1. Type of optical LVA used for assessment of aided reading function, and frequency of use of this LVA.
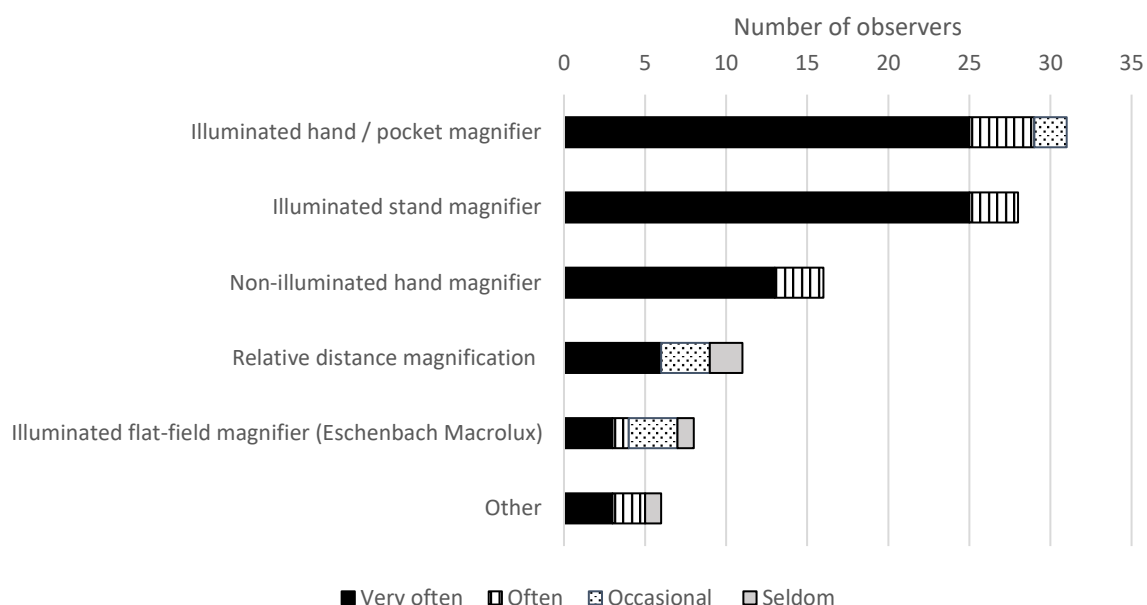
2.2 Procedures

Responses to two questionnaires are reported in the present analysis. A modified version of the Activity Inventory (Massof et al., 2007) encompassing thirty key goals for UK low vision patients (Tabrett & Latham, 2012) was assessed to represent perceived difficulty with vision-related activity limitation. Observers were asked to report the difficulty of any goal of at least some importance using any assistive devices (such as low vision aids), but without the assistance of another person. Difficulty was rated on a 5-point Likert scale (not difficult, slightly difficult, moderately difficult, very difficult, and impossible without assistance). Data were Rasch analysed to provide person measures in logits (Tabrett and Latham, 2011), with higher positive person measures indicating greater perceived ability. Depressive symptomatology was assessed with the 15-item Geriatric Depression Scale (GDS)(Sheikh & Yesavage, 1986). Responses to the dichotomous yes-no responses were again Rasch analysed to provide person measures.

Distance visual acuity was assessed binocularly using an externally illuminated Bailey-Lovie logMAR chart, and contrast sensitivity with a Pelli-Robson chart. Near reading performance was assessed binocularly with an MNREAD chart. The chart was initially placed at the standard working distance of 40cm, with observers wearing correction comprising their habitual distance spectacle prescription and a +2.50D reading addition where necessary. Where the largest print sizes could not be read at 40cm, working distance was reduced in log unit steps and reading addition increased appropriately. The minimum working distance employed was 8cm, at which the largest print size was +2.0 logMAR. It is noted that assessing reading performance at such short working distances might underestimate some observers' reading performance due to problems with chart illumination and maintaining any available binocularity. However, it was considered preferable to be able to record some level of reading function where possible rather than missing data. Reading function assessed in this way, under standard conditions and without assistance of an LVA, is considered here as 'clinical' reading function.

Reading performance 'aided' by use of the LVA was also assessed with an MNREAD chart, using a different chart to that used for clinical assessment (chart variants 1 and 2 were used). Observers read the chart using any habitual spectacle correction and LVA reported as commonly used for reading tasks, using one or both eyes as preferred, and at whatever working distance was required by the LVA. The manufacturer specified dioptric power of any low vision aid was noted as an indication of the level of magnification used, but the actual magnification provided by the aid as used by the participant was not calculated.

2.3 Analysis

Print sizes associated with clinical MNREAD parameters are specified in logMAR, since the assessment was carried out at specified working distances, allowing calculation of angular sizes. Print sizes associated with aided MNREAD parameters are specified in Sloan M, a physical print size, since working distance was not controlled.

Reading acuity and reading speed, taking errors into account, were calculated according to usual procedures (Legge, 2007). Maximum reading speed (MRS; words per minute) was determined as the mean of the fastest three readings obtained (or the fastest single reading if three print sizes could not be read), and critical print size (CPS) was determined as the smallest print size at which reading was achieved at 80% of the maximum speed (Patel et al., 2011). Reading index was calculated as the MRS divided by the CPS (McClure *et al.*, 2000; Tabrett and Latham, 2011).

The Reading Accessibility Index (ACC) was calculated as the mean reading speed for the print sizes 8-1M, divided by 200. For the clinical ACC measure, the print sizes included in the calculation were those read at the standard working distance of 40cm, and prints read at closer working distances were not considered (Calabrèse, Owsley, et al., 2016). The aided ACC considers the reading of these physical print sizes regardless of the magnification provided by the LVA or the working distance used. Therefore, the aided ACC compares the accessibility of print over the same physical print sizes as the clinical ACC, but with the assistance of an LVA rather than with 'standard' (+2.50D) reading spectacles.

3. Results

Descriptive statistics for functional measures are shown in Table 1. Clinical reading parameters of RA, CPS, and MRS were calculated including measures obtained at working distances shorter than 40cm for 19 observers. Whilst clinical reading parameters were measured in logMAR, values are also shown converted to Sloan M in Table 1 to allow comparison with aided parameters. Clinical MRS was based on reading speed for a single print size, rather than an average of three, for 22 observers who could read only a limited range of print sizes. Aided MRS was based on an average of three print sizes in all cases.

Table 1. Descriptive statistics of clinical visual function and self-reported measures.

	Mean	95% confidence interval
Clinical visual function		
Distance visual acuity (logMAR)	0.84	0.77, 0.91
Pelli Robson contrast sensitivity (logCS)	1.08	1.01, 1.15
MNREAD variables		
Clinical reading acuity (logMAR)	0.81	0.72, 0.90
Clinical reading acuity (M)	2.58	2.10, 3.18
Aided reading acuity (M)	1.03	0.78, 1.29
Clinical critical print size (logMAR)	1.02	0.95, 1.10
Clinical critical print size (M)	4.19	3.57, 5.04
Aided critical print size (M)	1.85	1.53, 2.16
Clinical maximum reading speed (wpm)	102	89, 114
Aided maximum reading speed (wpm)	114	102, 126
Clinical Reading Index (logMAR)	135	98, 173
Clinical Reading Index (M)	45	33, 56
Aided Reading Index (M)	126	102, 150
Clinical Reading Accessibility Index (ACC)	0.31	0.25, 0.36
Aided Reading Accessibility Index (ACC)	0.47	0.41, 0.52
Self-reported variables		
Geriatric Depression Scale (logits)	-2.09	-2.39, -1.79
Activity Inventory Goals (logits)	1.99	1.64, 2.34

Under clinical conditions, the mean ACC is 0.31 (95% confidence interval 0.25, 0.36). Use of an LVA results in a significant (t(99) -12.15, p<.001) improvement in reading accessibility to 0.47 (0.41, 0.52). The mean improvement from clinical to aided ACC was 0.16 (0.13, 0.18) (Table 2). Without an LVA,

25 of the visually impaired people have essentially no access to print (ACC≤0.05) and only 5 have relatively normal access to print (ACC≥0.8). With their LVA, only 5 individuals have no access to print in the size range, and 17 now have relatively normal access.

The ACC was also analysed with observers separated into those who self-reported a macular condition (n=57) and those with other causes of visual loss (n=43; Table 2). Those with macular conditions (n=57), had poorer reading function than those with non-macular causes of visual loss for RA (t(98) 2.2, p<.05) and MRS (t(98) -2.56, p<.05), although CPS was statistically similar (t(98) 1.36, p>.05). The clinical ACC for those macular conditions of 0.26 was lower (t(98) -2.10, p<.05) than the 0.37 for people with other conditions. An aided ACC value of 0.41 for those with macular conditions was also lower (t(98) -2.26, p<.05) than the 0.54 for those with other conditions. However, the improvement in ACC with an LVA was similar (t(98)-0.61, p>0.05) for those with macular conditions (0.15) and with other conditions (0.17).

Table 2. Summary of reading parameters for the whole sample, and for observers split into those with macular and with non-macular causes of visual loss. Means and 95% confidence intervals are given.

MNREAD parameter	All observers	Macular pathology	Mixed non-macular causes
Number	100	57	43
Clinical ACC	0.31 (0.25, 0.36)	0.26 (0.19, 0.33)	0.37 (0.29, 0.46)
RA (logMAR)	0.81 (0.72, 0.90)	0.90 (0.77, 1.02)	0.70 (0.57, 0.83)
CPS (logMAR)	1.02 (0.95, 1.10)	1.07 (0.96, 1.18)	0.97 (0.86, 1.07)
MRS (wpm)	102 (89, 114)	88 (71, 105)	120 (102, 138)
Aided ACC	0.47 (0.41, 0.52)	0.41 (0.36, 0.48)	0.54 (0.45, 0.63)
Improvement in ACC with LVA	0.16 (0.13, 0.18)	0.15 (0.12, 0.18)	0.17 (0.12, 0.20)

Correlations between the single-value reading indices (ACC and Reading Index) and key visual and self-reported outcomes are shown for the whole sample in Table 3. Reading indices are significantly related to visual function (visual acuity and contrast sensitivity) and to perceived visual difficulty (Activity Inventory). There was no significant relationship with depressive symptoms (GDS; p>.05). ACC and Reading Index perform similarly to each other in terms of their association with the different parameters.

Table 3. Correlations (two-tailed Pearson r) between visual function and questionnaire parameters and the reading parameters of reading accessibility (ACC) and Reading Index.

	Clinical ACC	Aided ACC	Clinical Reading Index	Aided Reading Index
Distance visual acuity	r=-0.83, p<0.01	r=-0.71, p<0.01	r=-0.55, p<0.01	r=-0.63, p<0.01
Contrast sensitivity	r=0.63, p<0.01	r=0.67, p<0.01	r=0.44, p<0.01	r=0.59, p<0.01
Activity Inventory Goals	r=0.63, p<0.01	r=0.59, p<0.01	r=0.59, p<0.01	r=0.48, p<0.01

A Bland-Altman plot showing the change in ACC as a function of the mean (Figure 2) demonstrates the significant average improvement in ACC with an LVA of 0.16 (dashed line), and also indicates that use of an LVA improved the ACC in 92% of cases. For 2 people there was no difference in ACC with and without an LVA, and for 6 people ACC was worse with their LVA (points below the solid line).
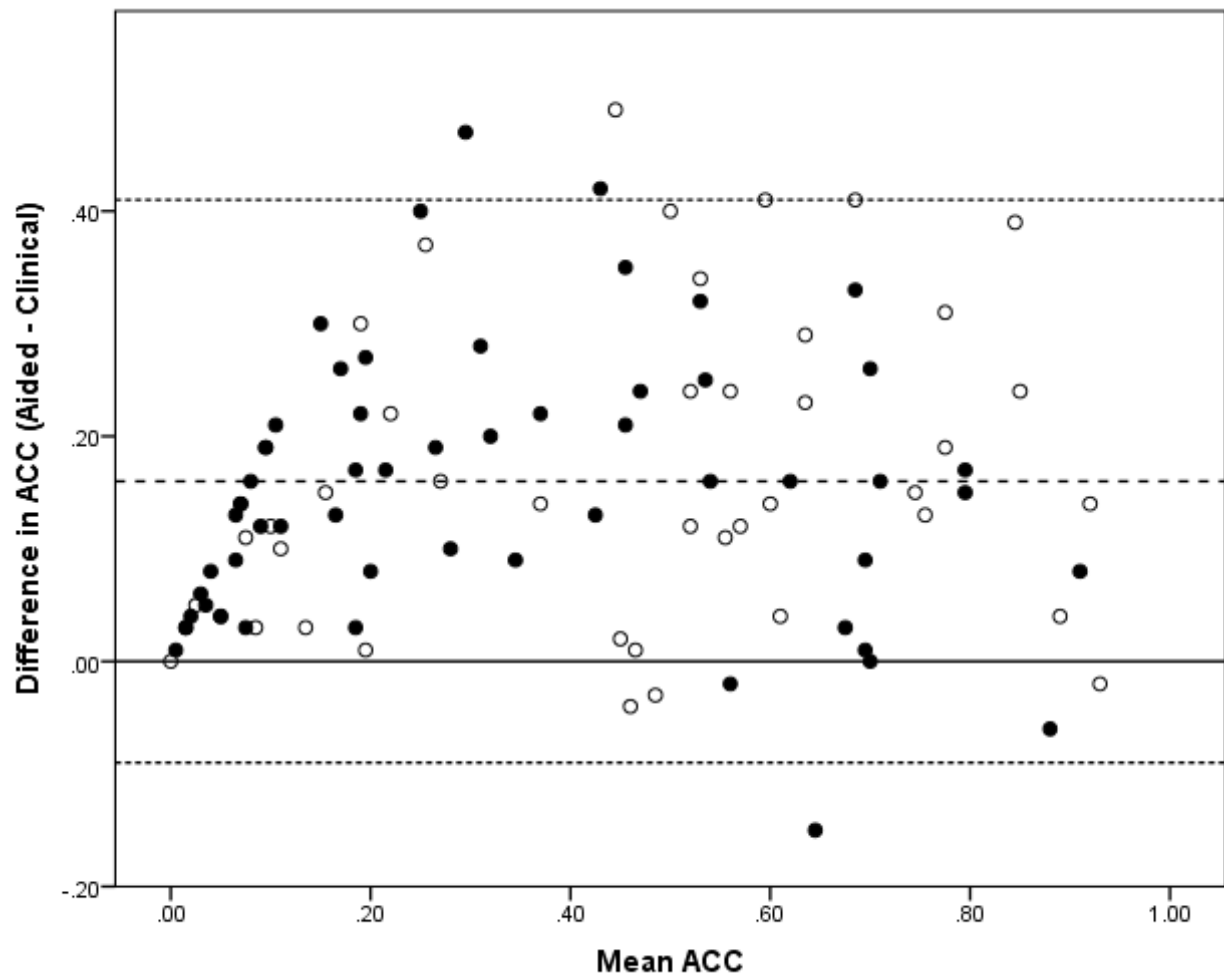
Figure 2. Difference between aided and clinical ACC, plotted against the mean ACC. Filled circles indicate observers with macular conditions, and open circles indicate observers with other conditions. The solid horizontal line indicates no difference between aided and clinical values, with points above this line indicating an improvement in ACC with an LVA. The dashed line indicates the mean difference (0.16) and the dotted lines the limits of agreement (±1.96 standard deviations).

The 6 people whose ACC is lower with their LVA than without were considered further. For five people, the ACC difference was marginal (-0.02 to -0.06). Two of these people had macular degeneration, one had glaucoma, one nystagmus, and one did not know the cause of their visual loss. These subjects all had relatively good reading performance with ACC sized prints without an LVA (clinical RA -0.04 to 0.4 logMAR, clinical MRS 108-208wpm), and all had contrast sensitivity of at least 1.05 logCS (range 1.05-1.75 logCS), suggesting that contrast sensitivity loss was not a barrier to reading (Whittaker & Lovie-Kitchen, 1993). They could all read at least two smaller physical print sizes with their LVA than without, such that the LVA improved their ability to read 'small' prints below the range considered by ACC. However, for these people the improvement in print size access

8

came at the expense of reading speed: two people had a lower MRS with their LVA than without (13 and 19 wpm slower), and the other three had a similar MRS (≤4 wpm difference) but read slower when averaged across the range of ACC print sizes. The LVAs used by these 6 subjects were a non-illuminated hand magnifier in three instances (+5D, +8D, +12D), a Macrolux illuminated flat-field magnifier for one person, and a close working distance and accommodation for one person.

The sixth individual for whom ACC was worse with than without a magnifier (a larger difference of -0.15) had poor technique when using their illuminated hand magnifier. They laid their magnifier on the page, and thus reading slowed down due to having the aid to manipulate as an extra task, but did not benefit from seeing any smaller prints. This person also reported using their magnifier only occasionally: it is not clear if their technique was poor because they used the magnifier infrequently, or if they used the magnifier infrequently because their technique was too poor for it to benefit their reading.

Considering all observers, the amount of improvement in ACC with an LVA shows no obvious variation across the range of mean ACC (Figure 2), indicating that the level of improvement in ACC with a magnifier does not depend on the clinical ACC. Similarly, the level of improvement in ACC with a magnifier does not correlate significantly with the baseline clinical visual variables of distance visual acuity, contrast sensitivity, reading acuity, critical print size or maximum reading speed ($p > .05$ in all cases).

4. Discussion

In this analysis, reading accessibility (ACC) values are determined for 100 people with visual loss of mixed causes. ACC represents the reading speed of an observer over a range of relevant print sizes based on a normalised reading speed of 200wpm. Therefore the typical ACC for normally-sighted young adults is 1.0 (Calabrèse, Cheong, et al., 2016; Calabrèse, Owsley, et al., 2016). ACC decreases in adults aged over 40 at a rate of 0.003 units per year, reaching a suggested value of 0.88 by the age of 81 years (Calabrèse, Cheong, et al., 2016). Average ACC values of 0.76 have been noted in a group of observers aged 55-85 years, and of 0.77 for bilateral pseudophakes (Calabrèse, Owsley, et al., 2016).

In comparison, the clinical ACC value of the visually impaired observers in the present study is 0.31 (Table 2), far below that of older observers as outlined above (0.76). Since ACC is a relatively recently proposed parameter, it has previously been determined in only three other samples of observers with some form of visual loss (Table 4). These have been one group with cataract (Calabrèse, Owsley, et al., 2016) and two groups with visual impairment, either from mixed causes of visual loss (Calabrèse et al., 2018), or central field loss specifically (Tarita-Nistor et al., 2018). It is clear that visual impairment has a marked impact on reading accessibility (0.31 – 0.36 across studies) as compared to a normative value of 1.0, and also compared to the sample with cataract (0.65). Analysis within the present sample does suggest that people with visual impairment due to macular conditions have poorer ACC than those with visual loss from other conditions (0.26 as compared to 0.37, $p < .05$; Table 2).

Table 4. Comparison of MNREAD parameters obtained without LVAs in different samples of visually impaired people (VIPs).

MNREAD parameter	Calabrese et al., 2016	Calabrèse *et al.*, 2018	Tarita-Nistor *et al.*, 2018

Observers	92, cataract	43 VIPs, mixed pathology	61 VIPs, central visual loss
Parameters presented	Mean ± standard deviation	Mean (95% confidence interval)	Mean ± standard deviation
ACC	0.65±0.18	0.36 (0.29, 0.42)	0.35±0.3
RA (logMAR)	0.24±0.16	0.77 (0.65, 0.89)	0.7±0.3
CPS (logMAR)	0.62±0.25	1.02 (0.90, 1.13)	0.9±0.3
MRS (wpm)	146±26	85 (71, 100)	102±60

The present analysis is the first to determine the impact of low vision aids (LVAs) on reading accessibility. Use of an LVA improves ACC significantly by an average of 0.16, from a mean of 0.31 without an LVA to 0.47 with an LVA. In this sample, 20% of people achieved some level of accessibility to print with an LVA (ACC >0.05) when they had no such accessibility without an LVA (ACC <0.05), and 92% of the sample showed an improved ACC with an LVA compared to without. Provision of LVAs as an intervention for reading therefore offers a significant and quantifiable improvement in reading accessibility for people with visual loss.

The improvement in ACC with LVA provision was very similar for those observers with macular conditions (0.15), compared to those with other causes of visual loss (0.17; Table 2). Therefore, the benefit of LVAs appears to be independent of the cause of visual loss. However, it should be noted that since those with macular conditions had poorer initial clinical ACC, given a similar level of improvement, they also had a slightly lower level of aided ACC (0.41) than people with other causes of visual loss (0.54; Table 2).

The only previous study to have determined the impact of an intervention on ACC values showed that a group of 18 subjects improved their ACC value by an average of 0.09 after perceptual learning training for reading rehabilitation (Tarita-Nistor et al., 2018). Given that the average ACC improvement with an LVA in the present study was 0.16, this suggests that as a sole intervention LVA provision may be more effective. It certainly highlights that the ACC would be a valuable outcome measure to consider in any randomised controlled trial comparing efficacy of different interventions for reading rehabilitation.

Note that despite the improvement gained with LVAs, reading accessibility is still lower than seen in patients with surgically-significant cataract (0.46 as compared to 0.65; Calabrèse, Owsley, *et al.*, 2016) or older observers (0.76; Calabrèse, Owsley, *et al.*, 2016). Limitations to reading performance with an LVA may be associated with reduced field of view through the magnifier (Whittaker & Lovie-Kitchen, 1993) or by the negative impact of the additional task of having the LVA to manipulate (Bowers, Cheong, & Lovie-Kitchin, 2007). Although 69% of the LVAs used here were illuminated, reduced illumination associated with the other 31% of LVAs that were non-illuminated could also have limited the benefits of LVAs (Bowers, Lovie-Kitchin, & Woods, 2001). Inadequate contrast sensitivity also has the potential to limit reading performance in the visually impaired observer, despite magnification (Latham & Tabrett, 2012; Whittaker & Lovie-Kitchen, 1993). Any central scotoma also impacts on reading ability (Whittaker & Lovie-Kitchen, 1993), not only because of reduced acuity in peripheral retina, but also through poorer fixation stability and accuracy of eye movements (Crossland, Culham, & Rubin, 2004). These additional factors may contribute to the poorer ACC values seen here in those with macular conditions as compared to those with other causes of visual loss.

There were a few individuals (n=8 in this sample) whose ACC does not improve with the use of an LVA. In one instance this was due to poor technique with magnifier use and highlights the

importance not only of providing LVAs, but also of training in their use and appropriate aftercare. In 5 further cases, while use of an LVA allowed smaller sizes of print to be read, this was at the expense of slower reading speed which reduced overall ACC. In addition to the factors outlined above with the potential for limiting performance with an LVA, experience in the use of magnifiers for reading could also influence performance. Although duration of LVA use was not recorded for these observers, all had experienced vision loss for at least 6 months. The ACC is therefore not without its limitations. Since ACC only considers print sizes as small as 0.4 logMAR, people with only slightly reduced reading function who use their magnifiers to allow them to read print smaller than 0.4 logMAR may not be seen to be benefiting from their LVA from an ACC measurement, although the LVA may be relevant to the patient achieving a desired task. Thus if the ACC were used as an outcome measure for an intervention in these patients, it may not successfully indicate the benefit that is being gained. In a similar vein, it has been noted (Tarita-Nistor et al., 2018) that ACC does not always distinguish between people with different impairments: those who read fast over a smaller range of prints could end up with the same ACC as someone who can read the full range of print sizes considered, but more slowly.

The improvement in ACC with the provision of an LVA varied considerably between individuals (Figure 2), raising the question of whether the amount of improvement to expect with an LVA can be predicted from baseline clinical measures. The amount of improvement in ACC with an LVA shows no obvious variation across the range of mean ACC (Figure 2), and does not correlate significantly with clinical acuity, contrast sensitivity or reading function variables. These findings indicate that it is not straightforward to predict who will benefit most from LVAs in terms of improvements to reading accessibility. Note however that the role of clinical reading acuity and contrast sensitivity in predicting aided reading acuity, and of clinical reading speed in predicting aided reading speed have been outlined elsewhere (Latham & Tabrett, 2012).

Although improvement in ACC with an LVA cannot be predicted from baseline clinical visual function, the relationship between ACC and visual function is significant (Table 3). Better acuity and contrast sensitivity are associated with higher ACC values, and the strength of association is similar for both clinical and aided values. The relationship with visual function is stronger in the current study (r 0.63-0.83) than in the sample with cataract examined by Calabrèse, Owsley, *et al.* (2016), where the correlation between clinical ACC and VA was -0.22, and with CS was 0.20. Calabrèse, Owsley, *et al.* (2016) also found a relationship between ACC and Timed Instrumental Activities of Daily Living related to reading (TIADL-R) of 0.60, similar to that observed here for vision-related activity limitations with the Activity Inventory. Reading indices have also been correlated to depressive symptoms (GDS), mentioned as a possible area of interest by Calabrèse, Owsley, *et al.* (2016), but the relationship is not significant. Although depressive symptoms do not relate to measured function as given by the ACC, it is a significant factor in explaining self-reported difficulty in this sample (Tabrett & Latham, 2011).

The use of a single numerical value to reflect both size and speed of reading has been suggested through the proposal of the Reading Index (McClure et al., 2000), and more recently the ACC (Calabrèse, Owsley, et al., 2016). The emphasis in the present study has been on the ACC, but Reading Index values were also available for comparison. ACC and Reading Index perform similarly to each other in terms of their association with key visual and self-reported outcomes (Table 4), suggesting that either could be valuable as a single-measure parameter for reading. However, the advantages of the ACC outlined previously have the potential to make this an easier value to implement in clinical practice, since derivation of a CPS value is not required, and the normalised values make interpretation of the values easier.

5. Conclusions

In this sample of visually impaired people attending for low vision assessment, average clinical reading accessibility (ACC) was 0.31, comparable with other samples of visually impaired observers (0.35-0.36; (Calabrèse et al., 2018; Tarita-Nistor et al., 2018)), and lower than that seen for people with surgically-significant cataract (0.65; (Calabrèse, Owsley, et al., 2016)). The ACC for the majority of observers (92%) improved with use of an LVA, with an average improvement of 0.16. However, even with an LVA reading accessibility remains low (0.47) compared to normally-sighted older observers (0.76; (Calabrèse, Owsley, et al., 2016)).

The ACC appears to be a useful single parameter that can provide a global indication of reading ability, and relates to both visual function and self-reported visual difficulty. It can quantify the benefit of low vision aids to a visually impaired person, and is a potentially useful outcome measure for assessment of reading rehabilitation interventions. However, improvements in ACC cannot easily be predicted from baseline visual function, and the ACC value may not be an appropriate outcome measure to use if the improvements an intervention are expected to make are predominantly outside the range of print sizes considered.

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