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Accessibility of Apple iPad for partially sighted users: pilot study

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Abstract

Purpose – *The purpose of this paper is to present the results of a pilot trial, investigating the accessibility provided by a tablet computer (Apple iPad) to individuals with visual impairment. The study was designed around an N-of-1 randomised controlled trial (RCT), which was replicated for 12 participants. It served as an opportunity to evaluate the use N-of-1 trials in studies involving people who are visually impaired.*

Design/methodology/approach – *The study centred round an N-of-1 RCT, comparing the accessibility provided by control equipment (Windows computer) against the intervention equipment (Apple iPad). Twelve participants conducted six tests on the equipment as per randomisation, followed by a quantitative-based evaluation and short interviews.*

Findings – *One-sided individual randomisation tests showed a significant result for overall satisfaction in favour of the tablet at the 0.05 significance level for seven of the participants. Participants identified several strengths of the iPad in helping a partially sighted user in accessing the internet: inbuilt zoom and magnification options; increased control as a result of the touch screen; and accessibility tools being built into the operating system. The main limitation suggested was the way the zoom function operates by enlarging the onscreen keyboard. This caused difficulties for those with more severe visual impairments using this function in inputting text.*

Originality/value – *There has been limited research to substantiate positive reviews of the tablet computer for low-vision users. The results of this pilot study gives evidence in support of these potential benefits, and demonstrates the importance of a more thorough investigation.*

Keywords *ipad, N-of-1, Randomized controlled trial, Tablet, Visually impaired*

Paper type *Research paper*

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Introduction

The World Wide Web and electronic mail are becoming increasingly integral aspects of today's society. From job applications, to house listings, and from utility bills to concert tickets, use of the internet is becoming an essential part of day-to-day living. This has two implications for people who are visually impaired or blind. First, access to the internet using contemporary technology may present barriers, thus excluding them from fully contributing in society. Second, once accessibility barriers have been overcome, the internet offers a quick access to information that was not readily accessible before (e.g. electronic versions of newspapers, job applications). For these reasons, there has been a great deal of research into how people with visual impairments access the internet, what they use the internet for and the barriers that they face. This paper explores these issues in relation to a Windows computer and the Apple iPad.

Chiang *et al.* (2005) reported on rapid advances in information technology over recent years. They observed how this means that access to computers and the internet is becoming increasingly essential for typical daily tasks, and also in participating in education and employment. They acknowledge that this has been a positive development in society, but suggest that it creates a barrier for visually impaired people, as they may experience difficulty in using this medium. This demonstrates the importance of research into the technology available

to help inform blind and visually impaired users which equipment will suit them best. Gerber (2003) discussed the value that representatives of the blind and visually impaired community place on computers and assistance technology, with one participant in their study expressing how, for some people, a computer is a luxury item, but for visually impaired people, it can fill a real need. Oppenheim and Selby (1999) focused specifically on the benefits of the internet to the visually impaired, claiming it has the power "to change the lives of disabled people".

Gerber (2003) conducted focus groups looking at the benefits and barriers of computer use for individuals who are visually impaired and found various common uses of technology. These included: employment; access to information (such as reading the daily newspaper); and social/community networks. The main barriers identified were the lack of training in the assistive technology available and lack of accessible information when choosing between products. Oppenheim and Selby (1999) highlighted some of the barriers encountered by the visually impaired in accessing the internet such as screen design, font size, colour and excessive use of graphics on a page making the main text difficult to read.

Recent advancements in technology which could potentially benefit blind and visually impaired people have been described in a number of online blogs and articles. The web site Mac-cessibilty has published a series of articles looking at accessibility options on Apple's iPad, in particular for the visually impaired (e.g. Mac-cessibility, 2010a, b). Peter Verhoeven from the web site Magnifiers.org (2010) describes how the iPad provides a good alternative to the expensive equipment which can be bought from assistive technology companies, as add-ons to the standard Windows computers. Similarly, a review of the iPad, which was conducted by the RNIB (2010), concluded that it "offers an excellent browsing experience".

More formally, a recent study by University of Birmingham (Douglas *et al.*, 2013) found that the iPad is being used as an educational tool amongst teachers of visually impaired students in the UK, with its inbuilt accessibility features (magnification and speech) being particularly well regarded, along with various third-party applications that the teachers were using.

Design

The pilot project

The aim of this pilot project was to investigate the accessibility provided by an Apple iPad for partially sighted users, and to collect data which could be used to help inform a larger study. The research was conducted through an N-of-1 randomised controlled trial (RCT), with the iPad being treated as the "intervention" and a Windows computer used as the "comparator". Whilst the principle aim was to look at any potential strengths and benefits of the iPad, the study also served as an opportunity to explore the use of N-of-1 RCTs in the social sciences.

iPad

Testing for this pilot project was conducted on the first generation Apple iPad. The Apple iPad is a tablet computer which is controlled by a multi touch display. Text is input using an onscreen keyboard which automatically appears when the user is seeking to enter text (although it is possible to buy additional tools, such as an external qwerty keyboard and Braille displays). There are a number of accessibility features which come as part of the operating system of the Apple iPad – these are described in Table I.

N-of-1 RCTs

N-of-1 RCTs are an example of a single subject study, which is an experimental research design constructed around the principle that the subject acts as their own control. In such a design, each participant is exposed to a control condition and an intervention condition, with comparisons between the two being made *within* the subject, rather than *between* subjects as in other experimental designs. Gast (2010) describes various types of single subject designs, such as a simple crossover trial involving one period of control and one period of intervention (AB), or a replication design involving multiple crossover periods (ABABAB).

Table I Description of some of the accessibility features available on the first generation Apple iPad

Name of accessibility feature	*Description*
"Pinch" magnification	It is possible to enlarge pictures and text on the screen by using a technique known as "pinching". Two fingers are placed onto the touch screen, and then dragged outwards, which in turn magnifies the content of the screen
VoiceOver	This is an inbuilt screen reader which uses "gestures" made via the touch screen. It also allows interaction with objects on the screen to enable the user to understand the location and context of, for example, web pages, icons. The speaking rate is adjustable and available in 36 languages. There is also a rotar available which allows control over how the screen reader will work through a document
Wireless Braille displays	The iPad supports Braille displays that use bluetooth wireless technology
Zoom	This function allows you to magnify the entire screen between 100 and 500 per cent, to help you see what is on the display. This will magnify everything, rather than just text and images
White on black	This changes the display so that all text appears white on a black background
Large text	The text size can be increased in calendar, contacts, mail, messages and notes, up to 56 point

A special type of single study design, which was adopted for this study, is the N-of-1 randomized trial. Backman and Harris (1999) explain the differences between this approach and other single-subject research designs. The N-of-1 randomized trial has its roots in medical research. For example, a doctor may investigate which dosage to give a patient by alternating between treatments and keeping a record of any necessary outcome data, such as blood pressure, comparing the outcomes and coming to a conclusion of which dosage best suits that patient. Unlike other single subject designs, no testing is conducted at a baseline level. To conduct an N-of-1 randomized trial, it is necessary to have an outcome which can be measured or scored. It is distinguished from other single subject designs in that it is important that the intervention treatment is expected to have a rapid effect on the individual, and that this effect will end at the point at which the treatment is no longer being administered (so that the impact of alternative conditions can be observed independently).

Although this methodology is most commonly used in medical literature, key organisations within educational research such as USA Institutes of Education Sciences (IES) have been encouraging the use of single-subject experimental designs in a social science context (IES, 2010).

One of the aims of this study was to see how well this approach could be adapted for research amongst visually impaired participants. A perceived advantage for applying an N-of-1 trial involving the visually impaired population was that it can take account of the variety of visual conditions and functions experienced. There are numerous eye conditions which affect individuals in different ways, and therefore this may cause variation in experience in using assistive technology. By grouping together participants in a conventional trial, the effects of the intervention may be lost by analysing the data across the group of participants. Edgington (1987) describes how, in trials involving multiple subjects, the effects on individuals can be missed due to the fact that the data are averaged across the heterogeneous group of subjects. However, by conducting an N-of-1 trial it is possible to look at the effects of the intervention on an individual.

Analysis of N-of-1 trials and randomisation tests

Analysing the results of single subject designs in behavioural sciences has been a contentious issue, with supporters and critics of a variety of approaches. Table II summarises the strengths and weaknesses of the three main methods used.

Table II Methods for analysing single-subject data

Method	*Strengths*	*Weaknesses*
Visual inspection of data	Do not need any statistical training to interpret the data Allows for continuous evaluation of treatments (e.g. Campbell and Herzinger, 2010)	Researchers have found low levels of agreement amongst those who participated in judging data More prone to type I errors Lack of a universal decision rule for accepting whether an intervention is effective or not (e.g. Ottenbacher ,1993; Campbell and Herzinger, 2010)
Parametric tests	Parametric tests typically have more power, and they are generally easier to administer Non-statisticians will usually be more familiar with parametric tests, and thus able to interpret the results more confidently	Repeated measures amongst single-subject trials could result in autocorrelation in the data This violates the assumptions made when applying parametric tests (e.g. Fisch, 2001)
Randomisation tests	Statistical tests which can be performed in the absence of a random sample More powerful than non-parametric tests (e.g. Edgington, 1987)	Lack of statistical power compared to parametric tests which can lead to Type II errors (e.g. Haardorfer and Gagne, 2010)

In accordance to suggestions made by Fisch (2001), a combination of both randomisation tests and visual inspection of data have been used in interpreting the data collected through this study, with the view that these two approaches will complement one another. Reference was made to Dixon *et al.* (2009) when applying visual inspection techniques, whilst the practical guide provided by Todman and Dugard (2001) was used when conducting randomisation tests. As an introduction, randomisation tests take into account the number of options in which the "treatments" (in this case allocation of iPad or Windows computer) could be arranged. For example (as described in more detail later), we can use the formula:

$$\text{No. of allocations} = \frac{Total\ treatments\,!}{(Allocation\ to\ treatment\,1!)(Allocation\ to\ treatment\,2!)}$$

to identify that there are 6!/3!3! = 20 possible allocations. Under the null hypothesis that there is no difference between the two treatments it should mean that the sequence of results we obtain will be totally unrelated to the how these allocations are arranged. In order to test this, we look at the difference in mean scores if the allocations had been arranged in any of the other 19 different possible allocations. Assuming that there is a difference between the two treatments, the highest mean difference should be detected through this allocation. There is a 1/20 chance that this could have happened by chance, and we therefore would conclude that the result is significant at the $100 \times 1/20 = 5$ per cent level.

Research questions

Three research questions were explored:

RQ1. Is there a difference in the level of satisfaction of partially sighted people in using Apple iPad to access information on the internet, in comparison to using the control equipment, a standard PC?

RQ2. What are the advantages and limitations of the Apple iPad for partially sighted users?

RQ3. How useful are N-of-1 RCTs for research amongst the blind and partially sighted community?

The design and methods of the pilot trial were written in a trial protocol submitted to the University of Birmingham Ethics Committee for ethical approval. Approval was received from

the ethics committee prior to commencing recruitment and starting the testing procedure. The research protocol was peer reviewed by an academic from Central Florida University with expertise in the use of single subject designs to evaluate educational interventions, and subsequently (minor) modifications were made to the design.

Participants

Participants were recruited with assistance from two UK charities (Royal National Institute of Blind People and Action for Blind People) and a specialist college for visually impaired students. A brief description of the study was prepared and sent to potential participants. Anyone who was interested was invited to contact the principal investigator for an information pack. This information pack contained a covering letter, information sheet, consent form and participant questionnaire. The information sheet (and associated consent form) provided full details of what participation would involve. The eligibility criteria were that the participants were eligible to be registered as partially sighted in the UK (similar to the World Health Organization definition of "low vision" and as described by RNIB, 2012) and that they were aged 18 years or over.

Trial design

Twelve participants were recruited to take part in six tests, split over two testing sessions. Each participant completed the same tests, and in the same order, but received differing allocations of equipment (i.e. either Windows computer or iPad) on which to complete each individual test, in accordance to their randomised allocation. These randomisations were conducted prior to starting the testing by an independent statistician from the York Trials Unit, UK. The randomisations were balanced to ensure that each participant would receive an equal allocation of three tests using a Windows computer and three tests using an iPad. This meant that, using the formula described earlier, there were (6!/3!*3!) = 20 possible combinations of allocations. Table III shows examples of possible allocations.

The twelve individual allocations were then allocated to the participants according to the order in which they were scheduled to complete testing session 1. The Windows computer used was a laptop and ran a Windows 7 operating system. It was decided this was the most appropriate comparator as Windows is the most commonly used operating system in work, education and homes in the UK, and Windows 7 was the most recent Windows operating system at the time (Netmarketshare, 2011).

Testing material

Before each session began, an introductory session to the equipment was given (in particular to the accessibility options available). This was scripted to ensure that each subject was exposed to the same conditions. Participants were assisted in setting up their devices to ensure that they were using the accessibility options to their maximum potential before continuing with the tests.

Test material was provided to participants as a point of reference, but instructions were also read out to participants, so they would not be restricted by how long it took them to read. Participants were tested individually, in well-lit rooms, away from noise and distraction, with each test being conducted on either a Windows computer or an iPad, in accordance to their allocation for that particular test. The tests were based around the participant planning a holiday. They were asked to use pre-determined web sites to look for train times, flights, accommodation, weather at their holiday location and travel guides.

Table III Examples of possible allocations

	Session 1			*Session 2*		
	Test 1	*Test 2*	*Test 3*	*Test 4*	*Test 5*	*Test 6*
Allocation 1	Laptop	iPad	Laptop	iPad	iPad	Laptop
Allocation 2	iPad	Laptop	Laptop	iPad	iPad	Laptop

Note: There are 20 unique possible allocations that the participants could have received

Answers to questions were given verbally to the researcher, who recorded them on a predetermined mark sheet. Different participants worked at different rates and a maximum time of 15 minutes was allocated for each test. Following each test, they were asked to complete a questionnaire evaluating how they found using the equipment, which consisted of several questions based on a Likert scale. This was completed by the researcher verbally reading out a series of statements and the participant selecting their response from a scale of 6 responses, ranging from "strongly agree" to "strongly disagree". This scale was printed in large print on paper for participants to reference. The questions covered various factors such as how confidently they felt that they were able to access all the necessary information, how well they felt they could navigate the web site and how well they could use specific features on web sites. These responses were then summed together to give an overall satisfaction score, and to give a series of repeated measurements over the six tests. The different statements which were used in the evaluation are presented as follows:

1. I was confident in using the equipment;
2. I was able to navigate the web sites;
3. I was restricted by the equipment I was using;
4. the answers I gave were accurate;
5. I was frustrated by the equipment at points through the test;
6. I was able to use drop down lists;
7. I was able to use pop-up windows;
8. I was able to filter results;
9. I was able to use search functions; and
10. I was happy with the speed in which I could complete the test.

Following each testing session a number of qualitative questions were asked to the participant, in order to gain a better understanding of the responses they had given, and to better inform the research team for any subsequent larger studies. Participants were asked to explain in more detail the specific benefits and limitations of the two pieces of equipment they had used. At the conclusion of each session, participants were given vouchers to compensate them for their time.

Controlling for bias and carryover effects

One of the main challenges of conducting a trial within a social science setting, rather than a medical one is the lack of control researchers have over the world around them. This was particularly true for this study, and there were a number of challenges that had to be overcome. First, in order to be able to take repeated measurements it was necessary for the different tests to be as similar to each other as possible. However, by asking the participants to access the same information online for each test, it was inevitable that they would start to remember the information they would be seeking to obtain, and their performance would improve. Instead it was decided that what was required was a generic set of tasks which the participants would work through, but with the content slightly changed for each one. Through using the same web sites to obtain the same amount of information on each occasion, the tests should be directly comparable. It was also important that the same web sites were used each time as some web sites are more accessible than others, which would obviously impact on performance. A further problem was that the participants would become more familiar with the web sites that they were visiting, which would undoubtedly bias the results through a carryover effect. To minimise this bias, it was decided to use the training period prior to starting the tests to work through an example test with the participants. This meant they would be starting the tests already familiar with the web sites that they would be visiting (it was thought that this would be representative of the majority of internet usage), and also the format and content of the tasks.

Results: participants and visual inspection of data

Table IV shows the demographics and relevant characteristics of the 12 participants recruited within the project. We were particularly encouraged that there was a wide range of preferred reading formats across the participants. As it was anticipated that the usefulness of the iPad could depend upon the degree of visual impairment of the participants, having such a wide range was highly beneficial for this pilot trial.

Visual inspection of data

Figure 1 shows an example of a scatter graph of the overall evaluation score for participant one over the six testing sessions. The lower the overall evaluation score, the more favourable the participant found using the equipment.

In this example, we can conclude that participant number 1 favoured the iPad, with the least positive evaluation (test 6) still being more positive than the most positive evaluation for the computer (test 3). Through visual inspection of repeated measures from all 12 participants we found that seven preferred using the iPad, one preferred using the Windows computer and the results for the other four were inconclusive.

Results: randomisation tests

Figure 2 shows the results of the individual randomisation tests for the 12 participants. To answer *RQ1*, the null hypothesis was tested that there was no difference between the overall

Table IV Descriptive statistics for demographics and characteristics of the 12 participants

Variable	*Total (n = 12)*	*%*
Gender		
Female	5	41.7
Male	7	58.3
Age		
18-24	5	41.7
25-35	2	16.7
35 +	5	41.7
Experience of using iProducts (iPhone, iPad or iPod touch)		
Yes	4	33.3
No	8	66.7
Preferred font size		
Normal to large print (12-17 point)	4	33.3
Large print (18-27 point)	6	50.0
Very large print (28 point and greater)	2	16.7

Figure 1 Scatter graph of overall evaluation for participant number 1

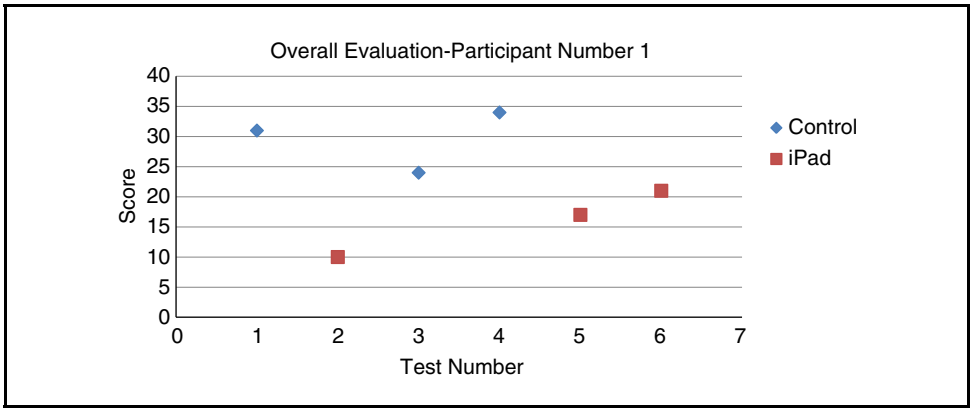
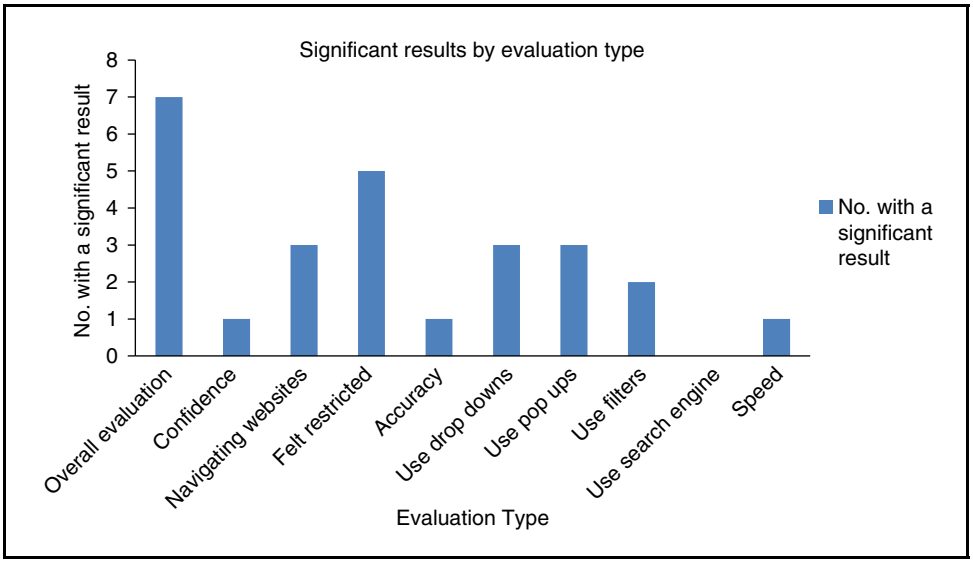


Figure 2 Number of subjects with a significant result, by evaluation type



satisfaction of participants when using the iPad, compared to their overall satisfaction in using the Windows computer. There is only sufficient power in the design to conduct one-sided randomisation tests, so the test was only looking for a significant difference in favour of the iPad. The individual randomisation tests were significant for seven of the participants, allowing us to reject this null hypothesis and conclude that the satisfaction of these seven was significantly higher on the iPad than the Windows computer. As we were using one-sided tests, it is not possible (and would be inappropriate) to test to see whether the satisfaction for the other five was significantly higher on the Windows computer than the iPad. It was found that those who had a significant result in favour of the iPad tended to have a smaller preferred reading format.

Randomisation tests were also conducted for the individual questions on the satisfaction survey (listed above). A number of significant results in favour of the iPad were obtained, with the most common being for how unrestricted the person felt using the equipment (five), lack of frustration in using the equipment (three), ability to navigate web sites (three) and use of drop down lists (three).

Results: analysis of interview questions

The interview questions at the end of each testing session provided a valuable opportunity to investigate further what the participants perceived to be the notable strengths and weaknesses of the Apple iPad, to them as a person with a visual impairment.

Inbuilt accessibility options

The most commonly discussed strengths centred on the iPad's inbuilt accessibility options. Examples of strengths included: zoom and magnification functions which the participants felt helped make the internet become more accessible; white on black contrast option; and the embedding of accessibility tools within the operating system. The participants contrasted this last example to their experience of using third-party accessibility software on a computer which would not always be compatible with the programme being used, and would quite often "crash" in the middle of a task. This can be particularly difficult for someone with low vision as they may not be able to see what is happening, but no longer have any assistive technology running to help them rectify the problem.

Advantage of the touch screen

It was highlighted how useful the touch screen element of the iPad was in enabling navigation of web pages. The explanation for this was that the participants did not have to locate a mouse

pointer, as this functionality is instead replaced by using your finger on the touch screen. Two participants reported an ease in being able to scroll through web sites on the iPad.

Other advantages

Several participants were positive about the ergonomic benefits of the iPad and the fact that they could position it in a favourable position to them, such as sitting by a window, or positioning it in front of them. Ergonomic design is an important consideration for low-vision people, who may rely on having equipment as close to them as possible. With the iPad computer the user has more control of its positioning, and they are naturally able to get closer to the screen, as they do not have to allow space for an external keyboard between them and the screen.

Although the Windows computer which was used in the testing session had a high-definition screen, some participants still observed that the screen on the iPad met their needs as low-vision users far better – despite the fact the iPad has a smaller screen. One participant who was an Apple Mac and Apple iPhone user, commented that the iPad could become more accessible by the introduction of a retina screen, as on the iPhone (this is now available on fifth generation iPads).

A participant who had used other iProducts referenced the common interface with other products from Apple, meaning you can get used to the accessibility options on an iPhone and iPad simultaneously.

Limitations

There were some limitations observed in the experience provided by iPad. The main criticism was the lack of functionality to use the zoom option at the same time as the VoiceOver (screen reader) function, as well as the difficulties faced in inputting text using the zoom function, as it would magnify the keyboard at the same time.

For those who were using the VoiceOver and zoom functions, they commented on how it would be useful to try using the iPad along with an external keyboard to help them enter any text, as they felt that this was the main limitation that they faced. This equipment is available, but the decision was made not to provide it in this pilot trial. It would be interesting to investigate this further in a full study.

Discussion and limitations

The analysis of the N-of-1 trials showed a significant positive effect for seven participants, using both the visual analysis and the randomisation test methods. This is an encouraging result for a pilot test, particularly considering that in most cases the participants had not used an iPad before. It was found that those participants with a more severe visual impairment were less likely to have a positive outcome. There are a number of possible explanations for this. First, those with more severe visual impairments needed to learn to use both the magnification software and screen reader software, and possibly the training period was insufficient. Second, those who used the zoom option struggled with the fact that the keyboard is also magnified, making it difficult for them to input text. Whilst this is a limitation of the iPad, there are ways around this such as the use of a bluetooth keyboard which were not investigated in this pilot study. Third, some users found it a challenge interchanging between the zoom functions and screen reader (due to the iPad's design, it was not possible to have both functions running at once). However, it is also worth noting that some managed to interchange between the two functions more readily than others – a reminder that although the technological capabilities may be present, it relies on the user being able to make use of them.

The interview questions at the conclusion of the testing sessions provided a valuable opportunity to hear the opinion of the participants on the features of the iPad that they thought would benefit them in accessing the internet. These proved to be extensive, and validated further the results found through the assessment tool used in randomised trial. There were suggestions too that the accessibility could be improved for those with more severe visual impairments by providing an external keyboard (particularly benefiting those with touch typing skills). One participant did

raise the question that a computer is more versatile than an iPad, and questioned whether it was realistic to make a comparison between the two. In this context it is important to remember that the comparison which was being made looked at the accessibility provided by the iPad specifically in accessing the internet.

It should also be noted that Windows have introduced into their latest operating systems (Windows 7 and 8) touch screen technology, and touch screen computers are becoming more readily available. The touch screen was one of the main advantages of the iPad that was identified by participants, in comparison to the Windows computer. Similarly, new generations of iPad have been released which incorporate additional features that visually impaired users may benefit from, such as a retina screen. These developments are something which should be investigated further in a larger study. This also demonstrates how difficult studies such as this one can be, with technology developing so rapidly.

Whilst there are many examples of N-of-1 studies in medical research and single-subject designs in social science literature, there were limited examples that could be adapted for this study. The main benefit of this design is that you are able to take small sample sizes (which is particularly useful in low-population groups such as visually impaired people), and through the design which incorporates both randomisation and repeated measures, it is possible to make statistical inferences. It is noted that there was only sufficient power in this design to conduct one-sided randomisation tests; however, it is rare to be able to conduct any statistical test with such small amounts of data.

Without the interview questions at the end of the testing sessions we would not really have understood what the perceived strengths and limitations were, something that would have been missed if it were simply an N-of-1 pilot study, but together, the two techniques complemented each other well.

One particular limitation of this study is that the participants were not recruited as a random sample, and this combined with the N-of-1 nature of the design makes it less valid to make inferences about the population as a whole. It should, however, be remembered that this project was a pilot trial, and its intention was to form the basis of a larger project.

Conclusion

This trial has shown that there is indeed some evidence that the iPad is beneficial for visually impaired people in terms of satisfaction in accessing the internet, when compared with the standard option of a Windows computer without additional accessibility software. Whilst there were features specific to the iPad that the participants found beneficial, there is evidence that one of the greatest advantages identified was the use of touch screen technology. The useful information gained from the project can be taken and applied to a larger trial with a familiar trial design which can be interpreted by the non-statistician more easily.

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