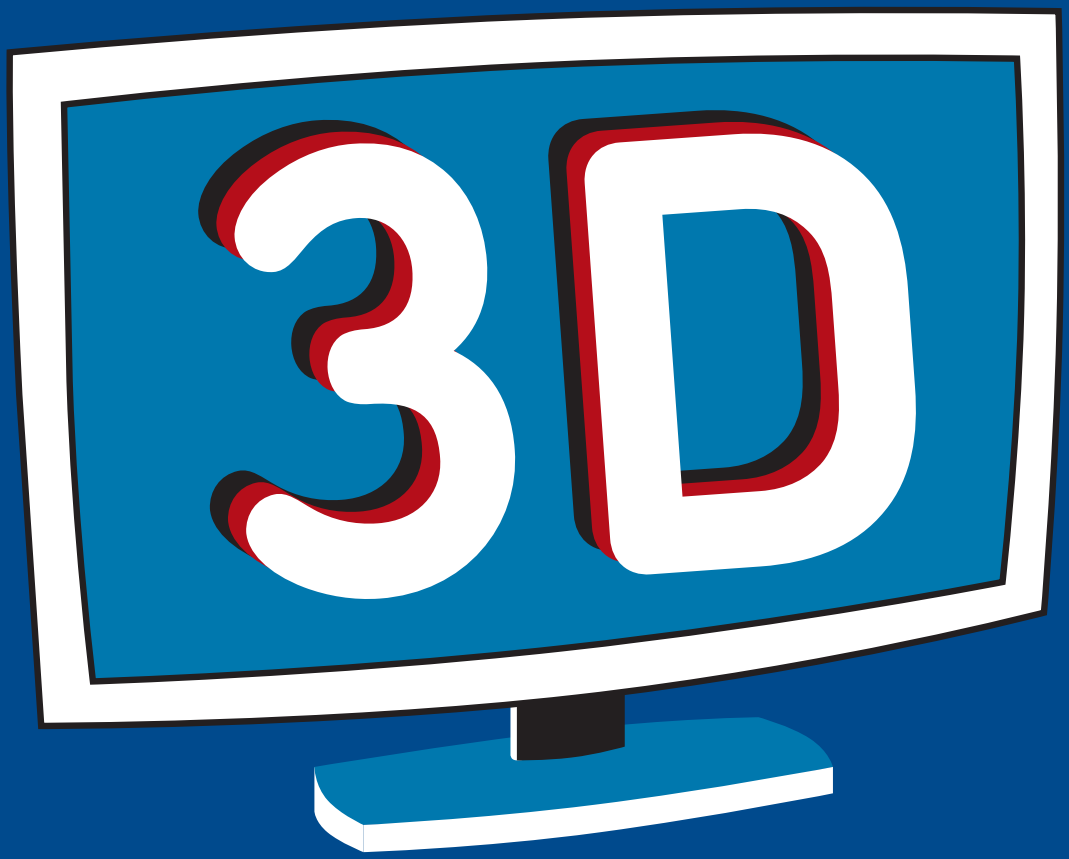

Scoping study report

Evaluation of partially sighted people's viewing experiences of 3D relative to 2D TV

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December 2010

RNIB supporting blind and partially sighted people

Prepared by mediaresearch

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Acknowledgements

Thanks to all interview participants and RNIB staff on the project steering group for their comments and suggestions.

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Please note: There are statistical graphs throughout this document, the content of which is explained in the text for those using screen reading software.

Foreword

The Royal National Institute of Blind People (RNIB) is the leading organisation representing the interests of two million people living with sight loss in the UK. RNIB has research evidence that blind and partially sighted people rely on, and want to use, television as much as their sighted peers. This is why RNIB has worked tirelessly to improve the accessibility of TV for blind and partially sighted people. RNIB is concerned about the impact of all new TV developments on accessibility. 2010 marked the arrival of 3D televisions and programming in the UK, and this led RNIB to ask questions about its impact on partially sighted people. What would happen to their viewing experience if, in the future, 3DTV was to become the norm? What does 3DTV mean for those partially sighted people who rely on their remaining sight to watch TV?

These issues have not yet been addressed by the broadcast and electronics industries. As a consequence, RNIB commissioned the independent academic research organisation, i2 Media, to conduct a 3DTV scoping study. The study set out to explore the benefits and drawbacks of 3DTV, relative to 2DTV, for partially sighted people and variances in experience depending on sight conditions. This study looked at the impact of short term exposure to 3DTV on partially sighted people. The results from these trials are encouraging, with only a few people reporting negative effects.

As 3DTV evolves and changes the way we watch television in our homes, RNIB challenges the industry to take responsibility for researching the impact of long term viewing of 3DTV on partially sighted people. We must ensure that people's viewing experience is not diminished when compared to 2DTV. If it is the same or even enhanced, then RNIB is happy for the new technology to be introduced as standard. However, if studies about prolonged exposure show that the viewing experiences of partially sighted people are not as good as for 2DTV, then technological and even regulatory solutions need to be put in place to ensure that all 3D channels and programmes remain available for 2D viewing in the future.

Leen Petré, Principal Manager, Media and Culture Department, RNIB

Executive summary

Background and introduction

This document reports primary independent research conducted by i2 media research limited (i2) commissioned by the Royal National Institute of Blind People (RNIB), to evaluate the experiences of partially sighted people when viewing 2D and 3D film clips from a Blu-ray disc. The scoping study was commissioned by RNIB to make a unique and urgently needed contribution to the debate about the introduction of 3DTV into the home with findings about the advantages and disadvantages for partially sighted people. Thirty-two partially sighted people and a control group of 43 fully sighted people took part in this study.

The benefits and drawbacks of 3D relative to 2D film clips for partially sighted people, who reported having any useful vision for watching TV, were explored using a repeated measures design with 3 viewing conditions:

- 3D with active 3D shutter glasses
- 2D with de-activated 3D shutter glasses
- 2D without 3D glasses

The viewing conditions were presented in a randomised order and without prompting the participants as to whether each viewing condition was 2D or 3D. Results from partially sighted people were compared with those drawn from the fully sighted sample.

Each presentation was evaluated using a series of questions asked to each participant after each viewing condition. The evaluative measures focused on whether the participants thought the presentation was in 3D or 2D, their perception of picture quality, their level of engagement/enjoyment, the extent to which they experienced any negative effects (disorientation, eye strain, headache, nausea) and, where applicable, whether the 3D glasses were comfortable.

Following the three viewings, participants were asked to evaluate the 3DTV viewing experience in relation to whether it provided a better viewing experience than their TV at home, whether they could see more or less in the 3DTV presentation than when they watch regular 2DTV and whether they thought they would be disadvantaged if 3DTV was the only TV available.

Qualitative responses from participants were also recorded following each viewing condition.

Main results

- Across both partially and fully sighted participants, 3D was preferred to 2D to view the film clips. This preference was not significant for the partially sighted sample, but was for the fully sighted sample.
- 3D received significantly higher picture quality ratings and presence/engagement ratings compared with 2D (without 3D glasses) in both samples. However, for the partially sighted sample, just wearing the glasses for the 2D film clip increased participants' ratings of the picture quality of the 2D film clip. Partially sighted participants' picture quality and presence/engagement ratings were not related to their level of sight loss or to whether their sight impairment was congenital or acquired.
- Participants from the sighted sample were significantly more likely to agree they would recommend the 3D experience than either of the other viewing conditions to their friends. Participants in the partially sighted sample were as likely to recommend the 3D experience as either of the other viewing conditions to their friends.
- Reported incidence of negative effects (dizziness/disorientation, eyestrain, headache and nausea) was low: most participants did not experience negative effects irrespective of the viewing condition. In the partially sighted sample, 3D did not significantly increase reports of negative effects relative to the 2D conditions. It is noteworthy that sighted participants were more likely to report negative effects than were partially sighted participants, even for the relatively short duration of presentation of the 3D clip. This result is not surprising in that negative effects arising directly from stereoscopic viewing would be most likely to affect people with stereoscopic vision.
- Evaluations of the 3D glasses were generally positive – participants in both samples tended to report that the glasses were comfortable and did not interfere with the way they usually watch TV.
- Participants' ability to discriminate between 2D and 3D was good although better for the fully sighted compared with the partially sighted sample. Participants in both samples were more likely to erroneously report that they had watched 3D whilst they had been watching 2D when wearing the de-activated 3D glasses. Fewer than half of the partially sighted sample correctly identified the film clip as 2D when they watched the 2D clip with de-activated 3D glasses.
- Almost half of the partially sighted participants who showed poor ability to discriminate 3D from 2D had been diagnosed with a condition that rendered them with monocular vision; thus their inability

to discriminate was not surprising. There were not a sufficient number of cases with each of the sight loss conditions to draw conclusions about which specific diagnosable sight conditions may lessen the experiential benefits of 3DTV viewing.

- Partially sighted participants were more likely to agree than disagree that 3DTV provides a better viewing experience than does 2DTV, though not to the same extent as did sighted participants.
- Based on their viewing of the four-minute film clip, partially sighted participants did not consider that they would be disadvantaged if 3DTV was the only TV available. The perceptions of partially sighted participants with respect to this question were more positive than those of sighted participants who perceived more disadvantages from 3DTV. Of course, if presented without any choice but to view 3DTV for extended periods, partially sighted participants may report differently.
- The majority of the study's partially sighted participants reported that they could make out as much detail when viewing the 3D film clips as they are usually able to at home with regular 2DTV. Their opinions were more mixed in relation to whether 3D helped them to see more, with broadly equal proportions agreeing and disagreeing.
- Without being informed that they had viewed 3D, partially sighted participants commented on the 3D film clip as being more vivid, sharp, clear and dynamic with more contrast and depth.
- When asked on what basis, if any, they would recommend others to try 3DTV, partially sighted participants referred to clearer and higher contrast images and to higher involvement and presence with the content.
- Negative comments made by some participants in both the sighted and partially sighted groups in relation to the 3D viewing experience focused on: eyestrain, reduced light from wearing the glasses, the design of the glasses and limited benefits of 3D considering its cost.

Contents

1 Introduction

1.1 Background

This document reports primary independent research, for a scoping study, conducted by i2 media research limited (i2) commissioned by RNIB, to explore the benefits and drawbacks for partially sighted people who report having useful vision for watching TV from three dimensional (3D) relative to two dimensional (2D) television. An additional goal was to explore how these potential benefits/drawbacks vary with various characteristics of sight loss to the extent possible given the relatively small scale of this study.

3DTV differs from standard 2DTV in that rather than one image being presented to both eyes, appropriate eye's views (left eye and right eye view) are captured by stereoscopic film/video cameras and presented to the relevant eye.

With current 3DTV technology there are two ways of delivering a separate left eye and right eye image, both of which rely on polarisation.

Active 3DTV: Here, left and right eye views are presented in sequence at very high speed (50 times per second to each eye). Active 3D glasses open and close alternate eyes' views in synchrony with the view being presented. So, when a left eye view frame is shown on screen the left lens of the glasses is opened and the viewer's left eye can see the screen. And when a right eye view frame is shown on screen, the right lens of the glasses is opened and the viewer's right eye can see the screen.

Passive 3DTV: Here, both left and right eye views are displayed at the same time with opposite polarisation (using polarising filters). When wearing passive 3D polarised glasses, the left eye view is only visible to a viewer's left eye and the right eye view to the viewer's right eye.

In addition to polarised displays for 3D images and video, research and development has been ongoing on autostereoscopic displays, where the viewer does not need to wear glasses to obtain the 3D effect. Here, the even columns of a display are directed to a viewer's right eye, and the odd columns of a display to the left eye, using lens arrangements on the display screen to appropriately direct each eye's view. Such lens arrangements are called lenticular lenses. The result of this approach is that the left eye view frames (at half horizontal resolution) and right eye

view frames (again at half horizontal resolution) are visible simultaneously to a viewer's appropriate eye. This approach is as used in Nintendo's, soon to be launched, 3DS portable gaming device.

To obtain the benefits of 3D display the viewer requires useful vision in both their left and right eyes and to have the ability to merge the two views (stereoscopic vision) through their visual system into one depthful whole. Some people have good vision in both eyes, but are unable to see 3D images because earlier problems with their vision, for example a squint, impeded the development of stereoscopic vision.

Any 3D display (active/passive with glasses or auto-stereoscopic) is also able to present 2D images by presenting the same view to both eyes.

1.2 Research objectives

- The research questions addressed in the project were to explore:
- Whether partially sighted people prefer 3DTV to 2DTV.
- Whether partially sighted people report any perceived differences in picture quality between 3DTV and 2DTV.
- Whether partially sighted people experienced a sense of engagement in 3D scenes relative to 2D scenes.
- Whether partially sighted people would recommend the 3DTV viewing experience to their friends.
- Whether there are any negative effects, specifically disorientation, eye strain, nausea and headache, as a result of viewing 3DTV.
- Whether the 3D glasses were comfortable and whether wearing them for a short period of time interfered with the way(s) in which partially sighted people normally watched TV.
- Whether partially sighted people can discriminate 3DTV from 2DTV.
- Whether 3DTV provides a better viewing experience for partially sighted people than 2DTV.
- Whether partially sighted people would be at a disadvantage if 3DTV was the only TV available.
- Whether partially sighted people could see more, or less, when watching 3D presentations than when they watched 2D presentations.
- Which aspects, if any, of 3DTV are preferred by partially sighted people and which aspects, if any, are disliked.
- How partially sighted people's experiences of 3DTV compared to sighted people's experiences, through the involvement in the study of a control group of sighted people.

2 Method

2.1 Design

To evaluate partially sighted people's viewing experiences of 3D relative to 2D film clips, an experimental lab-based study was conducted.

The study used a design in which two factors were studied, namely "viewing condition" and "sight condition".

- All participants experienced each of the three levels of the "viewing condition" factor. There were three levels of "viewing condition" which were presented in different orders for different participants:
- '2D without glasses' (participants shown the 3D Blu-ray film clip with the television 'dimension' setting adjusted to '2D'; no glasses were worn);
- '2D with de-activated 3D shutter glasses', (participants shown the 3D Blu-ray film clip with the television 'dimension' setting adjusted to '2D'; 3D glasses were worn but de-activated); and
- '3D with activated 3D shutter glasses' (participants shown the 3D Blu-ray film clip with the television 'dimension' setting adjusted to '3D'; 3D glasses were worn and activated). This condition used the Active 3DTV method of presenting 3D television, as described in the previous chapter.

For "sight condition" there were two levels (or groups):
- partially sighted;
- fully sighted.

Combinations of "viewing condition" and "sight condition" were explored for their effects on the dependent (outcome) variables outlined in Section 2.3 (Measures).

2.2 Equipment and film content

The film clips were presented to participants using a Samsung Blu-ray disc/DVD (BD-C6900) player connected to a Samsung 40'' (101cm) 3D LED TV display, purchased by i2 media research for the purpose of the research.

The content used in the study was an excerpt from the animated film, "Monsters vs. Aliens 3D" (Blu-ray 3D format). The 3D content appeared in 3D to participants when they wore a pair of Samsung 3D Active Glasses (SSG-2200AR) and the television 'dimension' setting was

switched to 3D. The same pair of glasses was worn by participants in the 2D with de-activated 3D shutter glasses. For this viewing condition, the 3D shutters in the glasses were simply de-activated. When de-activated, the glasses enable a wearer to see through both left and right lenses at the same time.

A four minute clip of the film was selected for presentation to participants. The same video clip was used for each of the three viewing conditions (2D without glasses; 2D with de-activated 3D shutter glasses and 3D with activated 3D shutter glasses).

The film clips were presented to participants in a darkened room.

2.3 Measures

Background information about participants' vision was collected prior to their taking part in the study. The following information was recorded:

Subjective/self-report background data

- Demographics (age, gender);
- Any history of epilepsy or seizures;
- Methods and visual aids to support TV viewing;
- Level of sight (using Network 1000 measurement: see 2.4.2);
- Development of sight loss;
- Sight condition (self report);
- Extent of TV use (to gauge motivation to TV viewing);
- Previous experience of 3D.

Objective background data

- Stereoscopic acuity test using the Randot, Random Dot Stereotest: see 2.4.2. This test measured people's ability to detect differences in distance using only stereoscopic disparity (the distance in 2 dimensions, between the representation of the same point on the left and right retinas). Participants obtained a score on the test indicating the smallest difference in stereoscopic disparity that they were able to detect reliably in images presented to each eye.

Following each of the three viewing conditions, post-test evaluations were taken. The evaluations consisted of a series of subjective/self-report questions on the following:

- Evaluation of whether the participant thought the viewing condition was 3D or 2D;
- Picture quality;
- Engagement/enjoyment;

- Negative effects (dizziness/disorientation, eye strain, headache, nausea);

Qualitative comments on:

- What participants liked and disliked about the viewing condition;
- Whether it was better or worse than viewing 2DTV at home.

After all viewing conditions, participants were asked a series of subjective/self-report questions consisting of:

- Preferred viewing condition (note: This was asked before participants had been told which viewing condition was 3D; they were asked which of the first, second or third viewings they preferred).

Once participants stated their preference, they were told which of the three viewing conditions had been in 3D. They were then asked:

- Whether the 3D presentation was a better viewing experience to the 2DTV they experience at home;
- Whether they would be disadvantaged if only 3DTV was available;
- Whether they could see more, or less, in the 3D viewing condition relative to the 2D viewing condition;
- On what aspects of the 3D viewing condition they would focus to persuade or dissuade someone to buy a 3DTV system.

2.4 Sample

2.4.1 Characteristics of the partially and fully sighted samples

Seventy five participants took part in the study; 32 were partially sighted and 43 fully sighted.

Partially sighted participants were recruited via RNIB and several other organisations supporting blind and partially sighted people in London. Fully sighted participants were recruited via their affiliation with RNIB, through advertisements on the internet and face to face on Goldsmiths' campus. All participants were paid £5.00 for taking part.

At recruitment, all participants were asked to bring along to their session any visual aids or corrective glasses that they normally used to watch television. This was verified when they arrived.

The partially sighted participants consisted of 18 males (56%) and 14 females (44%). These proportions were approximately balanced with those of the fully sighted sample, of which 23 (53.5%) were male and 20 (46.5%) were female.

The partially sighted sample was slightly older than the fully sighted sample. The median age range of the partially sighted sample was 35-44 years, and for the fully sighted group it was 25-34 years.

Overall, 45% of both samples combined normally watched TV for between 0-8 hours/week, 30.7% between 9-16 hours/week and 16% between 17-24 hours/week. The partially sighted sample reported watching more TV per week than the fully sighted sample (see Table 1).

Table 1: Number of hours of TV viewed per week

	Valid per cent of sample		
Hours/week	**Partially sighted sample (n=32)**	**Fully sighted sample (n=43)**	**Average across both samples (n=75)**
0-8	31.2	55.8	45.3
9-16	34.4	27.9	30.7
17-24	21.9	11.6	16
25-32	3.2	4.7	4
33-40	6.2	-	2.7
41+	3.1	-	1.3
TOTALS	**100%**	**100%**	**100%**

Sixty-five per cent of the sample as a whole had viewed 3D films or television on at least one occasion previously. A greater proportion of fully sighted participants (76%) than partially sighted participants (50%) reported having previously experienced 3D films or television.

None of the participants from either sample reported having photo-sensitive epilepsy.

2.4.2 Vision-related characteristics

Visual stereoscopic acuity was tested prior to the TV presentations using the Randot, Random Dot Stereotest. In this test, participants are presented with what appear to the naked eye to be ten rows of three circles. In each row of three circles, one circle has stereoscopic disparity (a difference in left and right eye views). When wearing polarised glasses, participants with stereoscopic vision are able to see

one circle on each row floating above or looking different to the other two. In the test, participants are required to indicate which of the three circles appears different to the other two circles on each row. The stereoscopic disparity associated with the 'floating' circle on each row decreases from the top row, to the bottom row. Participants' stereoacuity scores are based on their last correct choice, giving a score out of ten.

Five of the partially sighted group and 39 of the fully sighted group were able to give at least one correct answer on the test – meaning they were able to distinguish the circle with disparity from the other two. This indicated that five of the 32 partially sighted participants and 39 of the 43 sighted participants had some stereo vision. Participants who were unable to correctly indicate which of the three circles was different to the other two even on the first row, where the stereoscopic disparity was highest, did not receive a score. Not receiving a score, i.e. scoring 0/10, indicates that the participant has no stereo vision. The breakdown in stereoacuity scores by sample are summarised in Table 2.

Table 2: Distribution of participants' stereoscopic acuity scores

Randot score Score (acuity in seconds of arc)	**Number of partially sighted participants (n=32)**	**Number of fully sighted participants (n=43)**
(0) no stereo vision	27	4
1 (400)	2	1
2 (200)	1	0
3 (140)	1	3
4 (100)	0	1
5 (70)	1	9
6 (50)	0	3
7 (40)	0	4
8 (30)	0	8
9 (25)	0	2
10 (20)	0	8

Participants were asked to indicate which of a range of assistive aids/conditions/adjustments they used or made to watch their television. A summary of their responses is provided in Table 3.

There were very few reports by sighted participants of any adjustments to watch TV, apart from adjusting the lighting in the room (21%). A minority of sighted participants (14%) also reported using their residual sight to watch TV; indicating that they had not fully understood the

question as none of them reported sight problems. Partially sighted participants reported a range of adjustments.

Table 3: Adjustments reported by participants for viewing TV

When you currently watch or follow a programme/film on DVD/TV, do you use any of the following...	Per cent of partially sighted sample (n=32)	Per cent of fully sighted sample (n=43)
Use your residual sight to watch	78.1	14*
Wear special stronger glasses	3.1	9.3
Get closer to the TV screen	81.2	9.3
Use a magnifier	3.1	0
Adjust the screen settings	34.4	7
Adjust the lighting in the room	68.8	20.9
Use a large screen TV	50	11.6
Ask friends/family to assist by explaining what happens on screen	46.9	2.3
Pick up as much as I can from the sound	71.9	4.7
Use audio description	40.6	0
Make no adjustments	6.2	55.8

* a minority of sighted participants (14%) also reported using their residual sight to watch TV; indicating that they had not fully understood the question as none of them reported sight problems.

Participants' sight loss was categorised between 0 and 6. This categorisation was as used in the Douglas, Corcoran, and Pavey's (2006) Network 1000 research (Opinions and circumstances of visually impaired people in Great Britain: report based on over 1,000 interviews. University of Birmingham, Visual Impairment Centre for Teaching and Research, School of Education).

[0] No light perception

[1] In a room during daytime, you can tell by the light where the windows are
[2] You can see the shapes of the furniture in a room
[3] You can see well enough to recognise a friend if you get close to his or her face
[4] You can you see well enough to recognise a friend who is at arm's length away
[5] You can see well enough to recognise a friend across the room
[6] You can see well enough to recognise a friend across the road

Participants were asked to self-report how much, if any, vision they had using the statements listed above. Over 70% of the partially sighted sample reported that they could recognise a friend at arm's length, i.e. scored either [4], [5], or [6] using the above scale.

Participants were asked to self report any vision related problems that had been diagnosed and whether the condition was congenital or acquired.

The partially sighted participants had a wide range of eye conditions including albinism, cataracts, glaucoma, macular dystrophy/degeneration, nystagmus, retinitis pigmentosa and stargardt. Five partially sighted participants reported more than one condition. For example, one participant had albinism and nystagmus. Six of the partially sighted participants reported considerable loss of sight, or no sight, in one eye. For participants with vision in only one eye, stereoscopic presentation of images cannot support 3D depth perception.

Ten of the fully sighted participants reported corrected short sightedness, one reported corrected cataracts and one had undergone optic nerve fenestration (see Table 4 for the sight conditions reported by each group).

For 56% of the partially sighted sample, their sight condition was congenital, and for 44%, it was acquired/developed.

Table 4: Self-reported diagnosed visual conditions in each sample

Diagnoses	Partially Sighted	Fully Sighted
Cone-rod dystrophy	1	
Albinism	3*	
Amblyopia	3*	
Astigmatism		1
Bilateral disc atrophy	1	
Cataracts	3*	1**
Colour blindness	1*	
Glaucoma	4	
Hemianopia	1	
Macular degeneration	5	
Nystagmus	1*	
Optic nerve fenestration		1
Photophobia	1*	
Retinus pigmentosa	2	
Short sighted	1	10**
Squint	1*	
Stargardt	1	

* includes participant with more than one condition
** corrected to normal

2.5 Procedure

Each participant gave informed consent to take part in the study. Background information was collected from all participants prior to taking part.

Participants were seated in front of the 3DTV set. All fully sighted participants were seated at a distance of 343cm from the screen and partially sighted participants were asked to seat themselves at their preferred comfortable viewing distance, as they would at home. Their chosen distance varied between 40cm and 343cm (mean 143.65cm, SD 81.43cm).

Each participant was presented with the same four minute Blu-ray film clip for each viewing condition: 3D with activated 3D shutter glasses, 2D whilst wearing de-activated 3D shutter glasses and 2D without 3D glasses.

Participants were not told in advance of each viewing condition whether it was 2D or 3D. The order in which the viewing conditions was presented was randomised according to a predetermined schedule so that there were approximately equal numbers of participants receiving each of the six possible orders (A-B-C; A-C-B; B-C-A etc.). After each viewing condition, participants' subjective quantitative and qualitative responses were recorded (see section 2.3).

At the end of all three viewing conditions, participants were asked which one they preferred and on responding they were told which was in 3D. They were then required to answer a further series of questions evaluating their perception of the "3D with activated 3D shutter glasses" viewing condition. Before being thanked for taking part and debriefed, participants were asked whether they were willing to be re-contacted for further research for RNIB. All participants were paid £5.00 for their time.

3 Research results

For each of the research questions addressed in this study, a combination of statistical tests, both parametric and non-parametric, has been applied to the data. The main focus is on the partially sighted sample's data, to explore how their scores on various measures varied across the three viewing conditions.

Analyses that compare the partially sighted and fully sighted samples are also presented.

Before we present the results of the analyses for each research question in technical and statistical terms, we provide a simple summary to describe what the results mean in relation to each of the research questions.

3.1 Did partially sighted people prefer 3D to 2D?

Results summary: Half of the partially sighted sample preferred 3D with activated 3D shutter glasses to 2D with or without 3D shutter glasses that had been de-activated. This skew in preference, however, was not significant. A number of the partially sighted participants who instead preferred either of the 2D viewing conditions with or without 3D shutter glasses that had been de-activated were found to have conditions which would render the depth of the 3D presentation imperceptible, i.e. it would appear as 2D and thus identical to the other two conditions. In contrast, the fully sighted sample showed a significant preference for the 3D with activated 3D shutter glasses viewing condition.

At the end of the three viewing conditions participants were asked which they had liked most - the first, second or third presentation. Their response was re-coded into their favourite viewing condition based on the presentation order they experienced.

As shown in Figure 1, for both samples the 3D with activated 3D shutter glasses was favoured, more so by fully sighted participants (79%) than by partially sighted participants (50%).

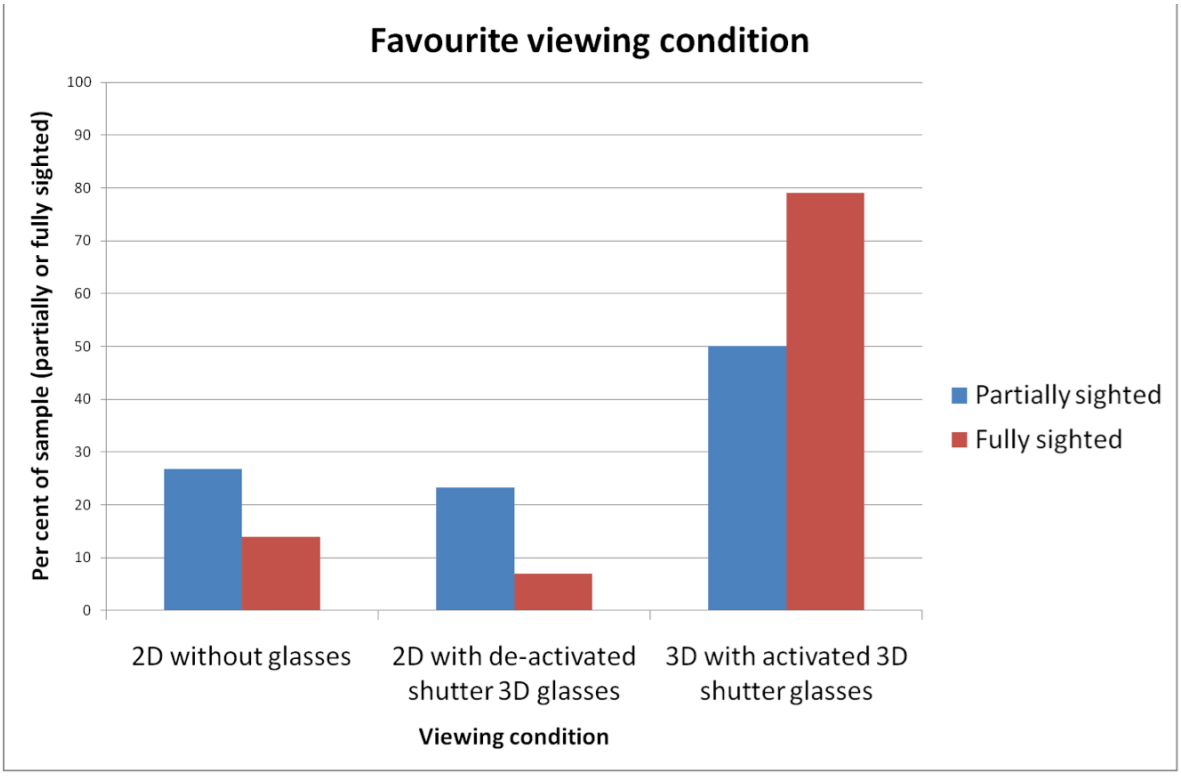

Figure 1: Favoured viewing conditions across the two samples

A Chi Square analysis of the cross-tabbed frequency data for both sight conditions was run to test for a significant difference in the number of people preferring one viewing condition over the others, compared to what would be expected if all viewing conditions were treated equally/endorsed by equal proportions of people (i.e. ~33% of the sample preferring any one viewing condition).

The analysis revealed significant differences in observed (compared to expected) proportions (Chi Square = 7.17, (df = 2), $p < .05$). However, when Chi square analyses were run for each sample, only the differences in (observed vs. expected) ratings given by the fully sighted sample were significant (Chi Square = 40.79, (df = 2), $p < .05$). Seventy-nine per cent of the fully sighted sample expressed a preference for 3D with activated 3D shutter glasses, 7% preferred 2D with de-activated shutter 3D glasses and 14% participants preferred 2D without glasses. For the partially sighted group there was no significant difference in (observed vs. expected) preference for viewing condition (Chi Squared = 3.80, (df = 2), ns).

That some partially sighted participants preferred 2D with or without 3D shutter glasses that had been de-activated over 3D with activated 3D shutter glasses suggests that it may be possible that some sight conditions may render 3D perception more uncomfortable or less

beneficial. There were not sufficient participants with specific eye conditions in the sample to rigorously explore this possibility but the data indicated that none of the partially sighted participants with the following conditions preferred 3D with activated 3D shutter glasses: monocular vision; hemianopia; and current, but not previous experience of, cataracts. Participants with monocular vision (vision in just one eye) would perceive all three video clips to be the same, regardless of viewing condition.

3.2 Did partially sighted people report any perceived differences in picture quality between 3D and 2D?

Results summary: Partially sighted people reported subtle differences in picture quality across the three viewing conditions. On average, they reported significantly better picture quality for 3D with activated 3D shutter glasses than 2D without glasses. In addition, simply wearing the de-activated shutter glasses improved some partially sighted participants' perceptions of the picture quality of the 2D clip. Whilst a minority of the partially sighted participants indicated that their preference was due to a perceived reduction in glare from the screen when wearing the shutter glasses, the difference could also be evidence of an expectation effect, for example participants reported picture quality to be better just because they were wearing glasses and knew they were taking part in a study on 3DTV. Picture quality ratings were not related to level of sight loss or to whether their sight loss was congenital or acquired. Partially sighted people's ratings of picture quality were similar to those found in the fully sighted sample.

To explore the effects of sight condition and viewing condition on perceptions of picture quality, participants were asked to evaluate the quality of the picture following each viewing condition using a scale from "excellent" [5] to "very poor" [1].

As shown in Figure 2, all average ratings of picture quality exceeded 4 ("good"). A series of three paired sample t-tests were run with only the partially sighted sample to explore whether there were any perceived picture quality differences between the viewing conditions. Only one paired samples t-test was significant (3D with activated 3D shutter glasses vs. 2D without glasses): participants rated 3D with activated 3D shutter glasses significantly more highly for picture quality (4.58; SD = .56) compared with 2D without glasses (4.29; SD =.64) ($t = 2.19$, $df = 30$, $p < .05$). That the mean score (4.35) for 2D with de-activated shutter 3D glasses did not differ significantly from either of the other viewing conditions suggests that wearing the glasses improved perceptions of

the picture quality, either through the glasses reducing perceived glare from the screen for a minority of participants or through increased expectations.

Using just the partially sighted sample, Pearson correlations were run to explore the association between quality ratings of 3D with activated 3D shutter glasses and the Network 1000 index scores (for proxy levels of usable vision). There was no significant relationship between these two variables (r = .28, n = 31, ns). Independent samples t-test revealed no significant difference in quality ratings of 3D with activated 3D shutter glasses between partially sighted participants with acquired (mean = 4.64) vs. congenital (mean = 4.52) sight impairment (t = -.55, df = 29, ns).

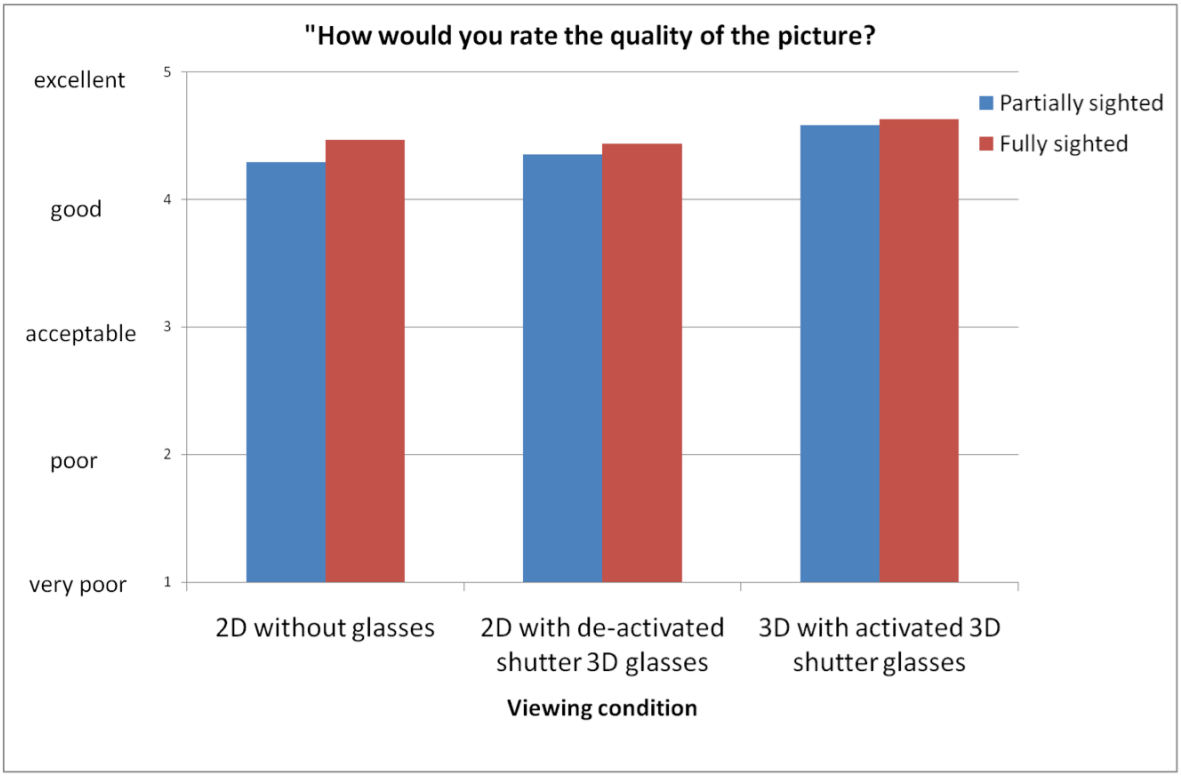

Figure 2: Quality ratings for the viewing conditions across the two samples

When both samples were explored and compared using a repeated measures ANOVA, there was a significant main effect of viewing condition: irrespective of sight condition, higher quality ratings were given for 3D with activated 3D shutter glasses compared to 2D with or without 3D shutter glasses that had been de-activated (3D with activated 3D shutter glasses: mean = 4.60, SD = .08; 2D with de-activated shutter 3D glasses: mean = 4.40, SD = .08; 2D without glasses: mean = 4.38,

SD = .07) and this difference in mean scores, albeit small, was significant ($F(2,144) = 3.79$, $p < .05$).

However, there was no main effect of sight condition: the picture quality ratings of the fully and partially sighted samples (across viewing condition) did not differ significantly ($F(1,72) = .910$, ns). In addition, there was no significant interaction between sight condition and viewing condition on picture quality ratings ($F(2,144) = .257$, ns).

3.3 What was partially sighted participants' engagement/sense of presence in 3D relative to 2D scenes?

Results summary: Partially sighted people reported significantly higher engagement/presence for 3D with activated 3D shutter glasses than either of the 2D viewing conditions (with or without 3D shutter glasses that had been de-activated). Engagement and presence ratings were not related to level of sight loss or to whether their sight loss was congenital or acquired. Whilst the pattern of partially sighted people's ratings of engagement/presence was similar to that found in the fully sighted sample, fully sighted participants reported even higher engagement/presence ratings for the 3D with activated 3D shutter glasses viewing condition.

To explore the effects of sight condition and viewing condition on their engagement/sense of presence for each viewing condition, participants were asked to indicate using a 5-point scale how strongly they agreed or disagreed with the presence statement "I had a sense of being in the scenes displayed".

The mean ratings of each viewing condition across the two samples are shown in Figure 3. These mean scores show how presence was rated close to '3' ("neither agree nor disagree") for the two 2D conditions with or without 3D shutter glasses that had been de-activated, but increased to almost '4' ("agree") for 3D with activated 3D shutter glasses.

A repeated measures ANOVA indicated that irrespective of whether they were sighted or partially sighted, participants reported experiencing a significantly greater sense of presence in the 3D with activated 3D shutter glasses viewing condition compared with the 2D viewing conditions with or without 3D shutter glasses that had been de-activated ($F(2,144) = 33.18$, $p < .05$; 3D with activated 3D shutter glasses: mean =

3.67, SD = .13, 2D with de-activated shutter 3D glasses: mean = 2.86, SD = .12; 2D without glasses: mean = 2.70; SD = .11).

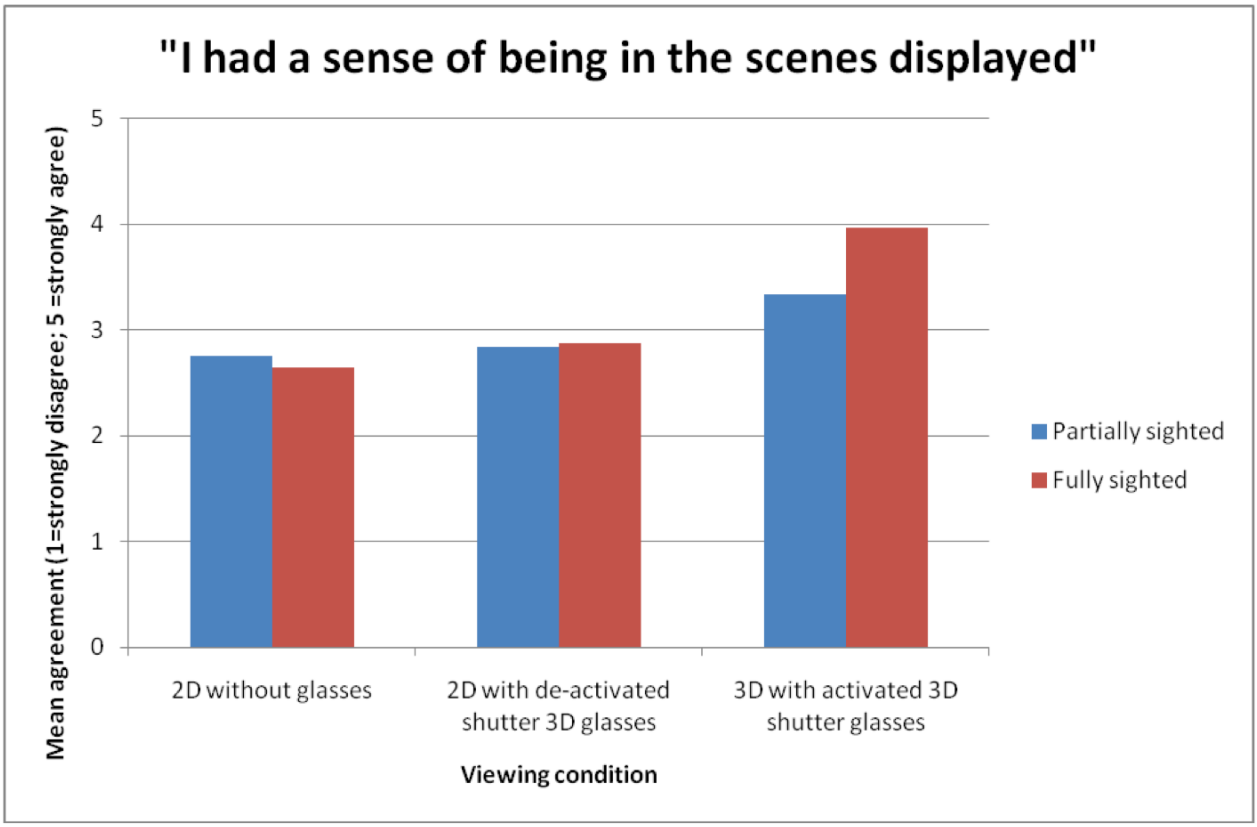

Figure 3: Presence ratings for three viewing conditions

Considering only the partially sighted sample, a series of paired samples t-tests revealed that partially sighted participants gave significantly higher presence ratings for the 3D with activated 3D shutter glasses viewing condition compared with either of the two 2D presentations ($t = 2.32$, ($df = 31$), $p < .05$ and $t = 3.05$, ($df = 31$), $p < .05$ respectively), which in turn did not differ significantly from each other ($t = .48$, ($df = 31$), ns).

There was no significant correlation between presence ratings for the 3D with activated 3D shutter glasses viewing condition and level of sight loss (as measured using Douglas, Corcoran, and Pavey's 2006 Network 1000 scale) ($r = .04$, $n = 32$, ns) and no significant difference in presence ratings between participants with acquired (mean = 3.36) and congenital (mean = 3.33) sight impairment ($t = -0.6$, ($df = 30$), ns).

Whilst there were no overall differences in sense of presence ratings between fully and partially sighted participants ($F(1,72) = .99$, ns), there was a significant sight condition to viewing condition interaction

($F(2,144) = 4.80$, $p < .05$). Exploring the mean scores in Figure 3, above, reveals that:

- both samples gave similar ratings for the 2D viewing conditions with or without 3D shutter glasses that had been de-activated; and
- sighted participants gave higher ratings for 3D with activated 3D shutter glasses than did partially sighted participants.

3.4 Would partially sighted people recommend the 3DTV viewing experience to their friends?

Results summary: Partially sighted participants tended to agree that they would recommend the experience to their friends irrespective of which viewing condition they experienced. There was no difference in their ratings between the three viewing conditions – they were about as likely to recommend either of the 2D viewing conditions (with or without 3D shutter glasses) as they were the 3D with activated 3D shutter glasses viewing condition. In contrast, the fully sighted sample were significantly more likely to recommend to their friends the 3D with activated 3D shutter glasses viewing condition compared to the other two viewing conditions.

Following each viewing condition, participants were asked to indicate, using a 5-point scale, how strongly they agreed or disagreed with the statement “I’d recommend the experience to my friends”. Analyses explored whether there were differences in these ratings between viewing conditions and sight condition.

As illustrated in Figure 4, for all viewing conditions participants tended to agree that they would recommend the experience to their friends and these ratings were highest for the 3D with activated 3D shutter glasses viewing condition.

Across both samples, repeated measures ANOVAs revealed that participants viewing 3D with activated 3D shutter glasses were significantly more likely to agree that they would recommend the experience to their friends ($F(2,144) = 15.10$, $p < .05$; 3D: mean = 3.95, SD = .11, 2D with de-activated shutter 3D glasses: mean = 3.35, SD = .12; 2D without glasses: mean = 3.6; SD = .10).

There were no differences in ‘recommend’ scores between fully and partially sighted participants ($F(1,72) = 1.03$, ns), however this did vary significantly as a function of viewing condition (i.e. there was a significant sample to viewing condition interaction: $F(2,144) = 5.02$, $p < .05$). For the partially sighted sample there were minimal differences in

‘recommend’ scores across the three viewing conditions, however, for the fully sighted sample, ‘recommend’ ratings for the two 2D conditions (with or without 3D shutter glasses that had been de-activated) were similar to each other and were notably lower than for the 3D with activated 3D shutter glasses viewing condition.

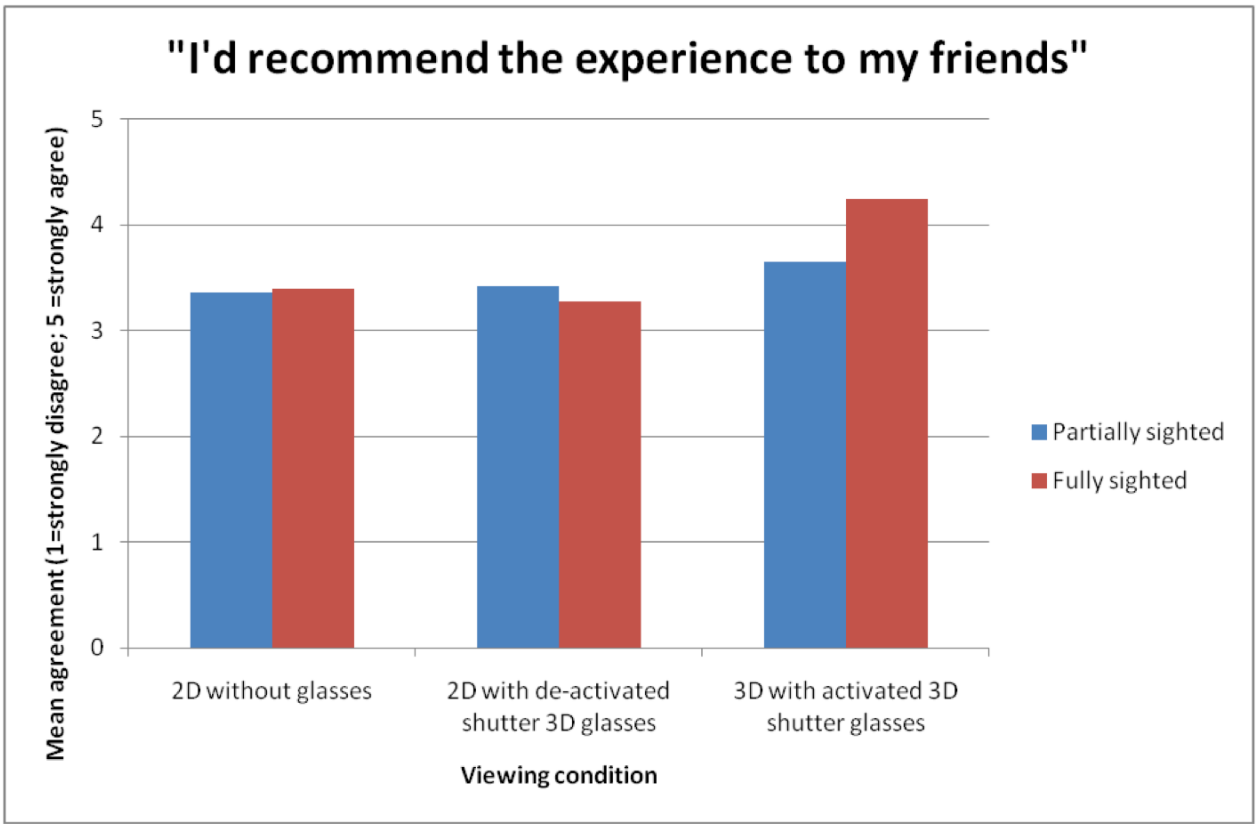

Figure 4: Mean ‘recommend’ scores for the viewing conditions

The partially sighted sample’s scores for each viewing condition were analysed separately using a series of paired samples t-tests. The results indicated no significant differences in ‘recommend’ scores between any of the paired viewing conditions (3D with activated 3D shutter glasses vs. 2D with de-activated shutter 3D glasses: t = 1.13, (df = 31), ns); 3D with activated 3D shutter glasses vs. 2D without glasses: t = 1.39, (df = 30), ns); 2D with de-activated shutter 3D glasses vs. 2D without glasses: t = .37; (df = 30), ns). This is consistent with the significant sight condition to viewing condition ANOVA result described above, and indicates that the main effect of viewing condition identified in the ANOVA could be attributed to the fully sighted participants’ ratings.

3.5 Were there any negative effects as a result of viewing 3DTV?

Results summary: Partially sighted participants did not generally report dizziness/disorientation, eyestrain or headache as a consequence of viewing the film clips in any of the three different viewing conditions. Watching the clip in 3D with activated 3D shutter glasses did not significantly increase their reporting of these negative effects relative to the other viewing conditions (2D with or without 3D shutter glasses that had been de-activated). Furthermore, partially sighted participants reported significantly more dizziness/disorientation relative to the fully sighted participants in the 2D viewing conditions. Sighted participants' reports of negative effects were stepped, with negative effects to 3D with activated glasses being higher than to the 2D with shutter glasses de-activated condition which in turn was higher than to 2D without glasses condition. For partially sighted participants reports of negative effects were more variable across viewing condition. It is important to note that longer film clips might have elicited more pronounced negative effects in both the partially and fully sighted samples. Eye strain and headache were the only negative effects for which sighted participants reported higher incidence than did partially sighted participants in the 3D viewing condition.

To explore whether participants experienced any negative effects of viewing 3D with activated 3D shutter glasses compared with 2D with or without 3D shutter glasses that had been de-activated, after viewing each presentation participants were asked to report on a 5-point scale the extent to which they agreed or disagreed that they experienced each of four specific negative effects (dizziness/disorientation; eyestrain; headache; nausea).

As illustrated in Figures 5 a-d, all mean ratings of negative effects were relatively low (score of 2 or less which corresponds to the 'disagree' categories) indicating relatively low incidence of negative effects from any of the viewing conditions. For the fully sighted sample, the means indicated a stepped increase in ratings of each negative effect from 2D without glasses to 2D with de-activated 3D shutter glasses to 3D with activated 3D shutter glasses. However, for the partially sighted sample, this pattern was observed only for eyestrain; the pattern of ratings for the three other negative effects was inconsistent. The analyses for each negative effect are described in the following sections.

3.5.1 Dizzy/Disorientated

For the statement “I was (beginning to feel) dizzy and disorientated”, there was no main effect of viewing condition ($F(2,146) = 2.38$, ns), but there was a significant main effect of sight condition: the partially sighted sample gave significantly higher ratings of ‘dizziness/disorientation’ than did the fully sighted sample ($F(1,73) = 5.14$, $p < .05$; partially sighted: mean = 2.08; SD = .10; fully sighted: mean = 1.78, SD = .09). Furthermore the interaction between sight condition and viewing condition was also significant ($F(2,73) = 4.90$, $p < .05$) which reflected the contrast between the stepped increase in ratings from the fully sighted condition and the flatter pattern of consistently higher ratings from the partially sighted sample.

To explore this further in the partially sighted sample, paired samples t-tests on their data indicated that there were no significant differences in mean ratings of dizziness/disorientation for each paired comparison of viewing condition, namely:

- 3D with activated 3D shutter glasses vs. 2D with de-activated 3D shutter glasses ($t = .18$, ($df = 31$), ns)
- 3D with activated 3D shutter glasses vs. 2D without glasses ($t = -.44$ ($df = 31$), ns)
- 2D with de-activated 3D shutter glasses vs. 2D without glasses ($t = -.63$; ($df = 31$), ns).

This suggests that 3D with activated 3D shutter glasses did not increase dizziness/disorientation relative to 2D with or without 3D shutter glasses that had been de-activated for the partially sighted sample.

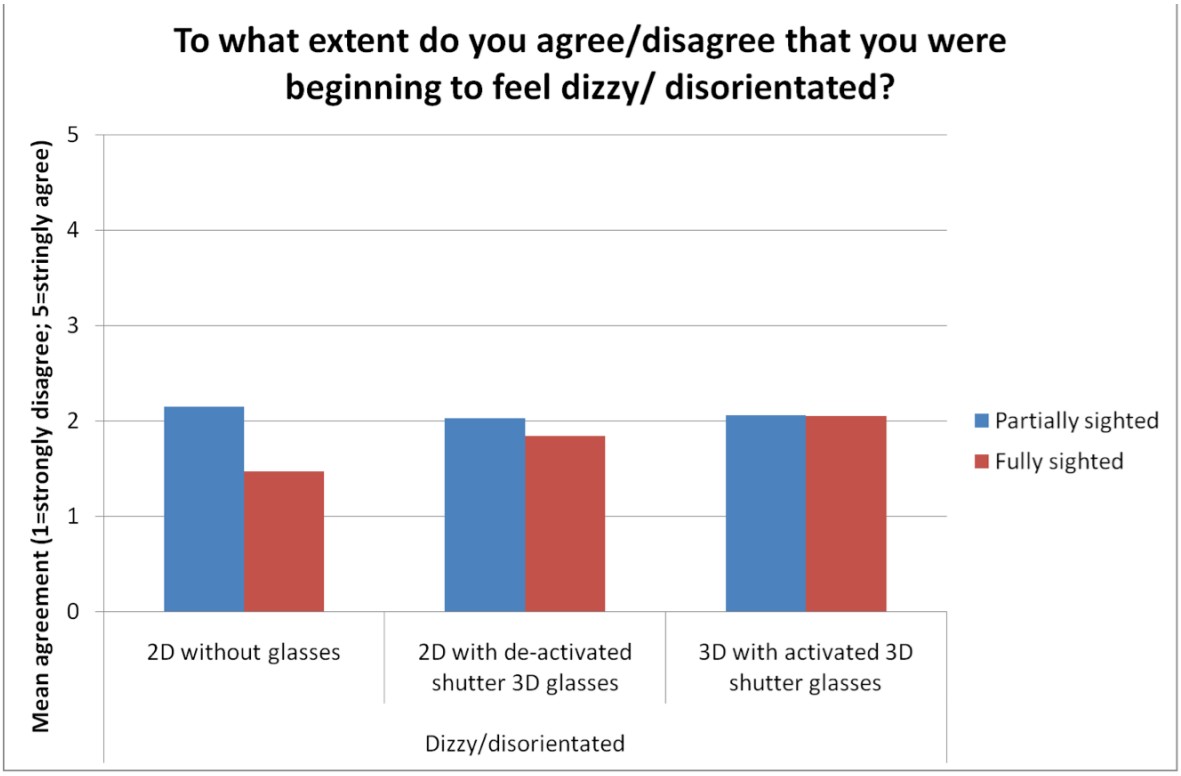

Figure 5a: Mean scores on dizziness/ disorientation for the three viewing conditions

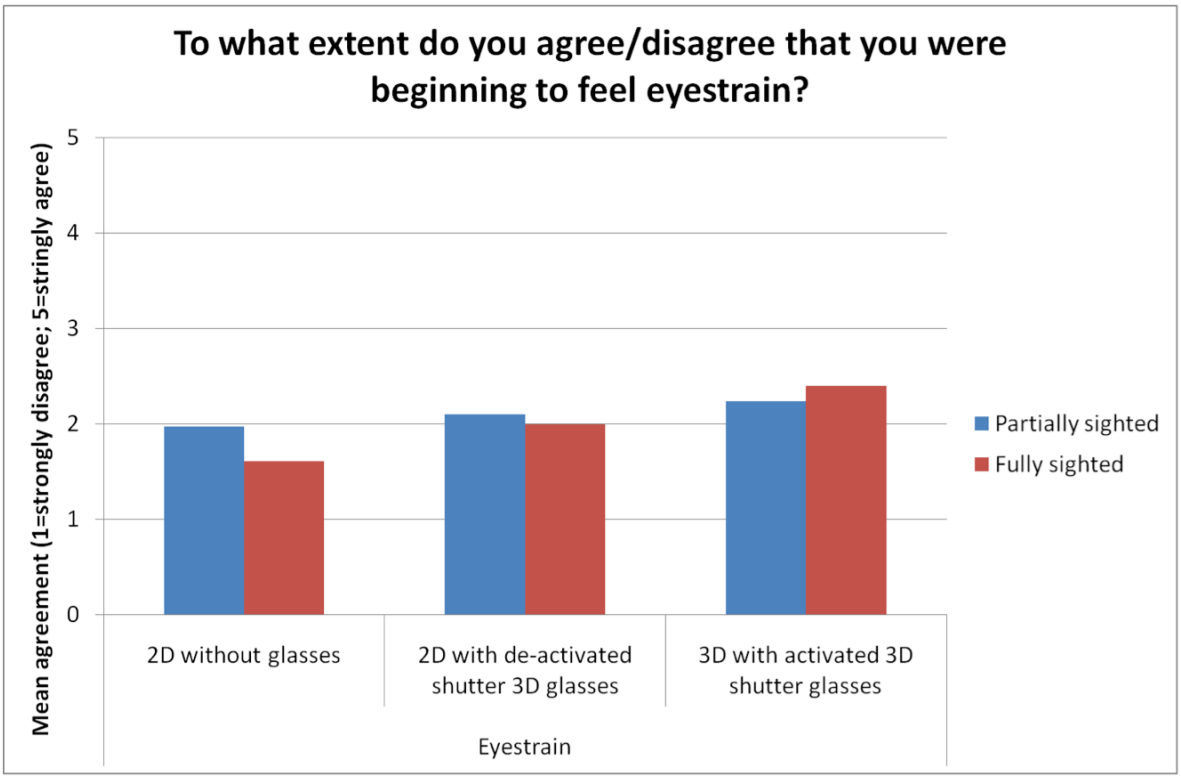

Figure 5b: Mean scores on eye strain for the three viewing conditions

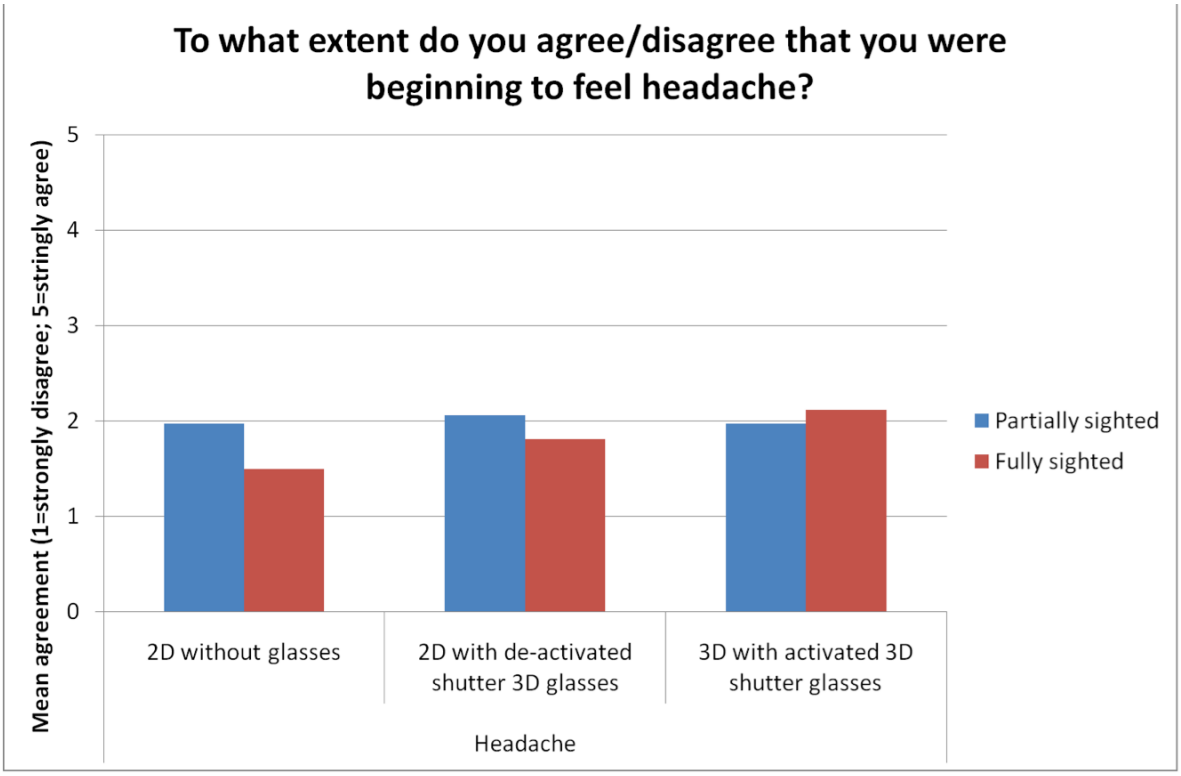

Figure 5c: Mean scores on headache for the three viewing conditions

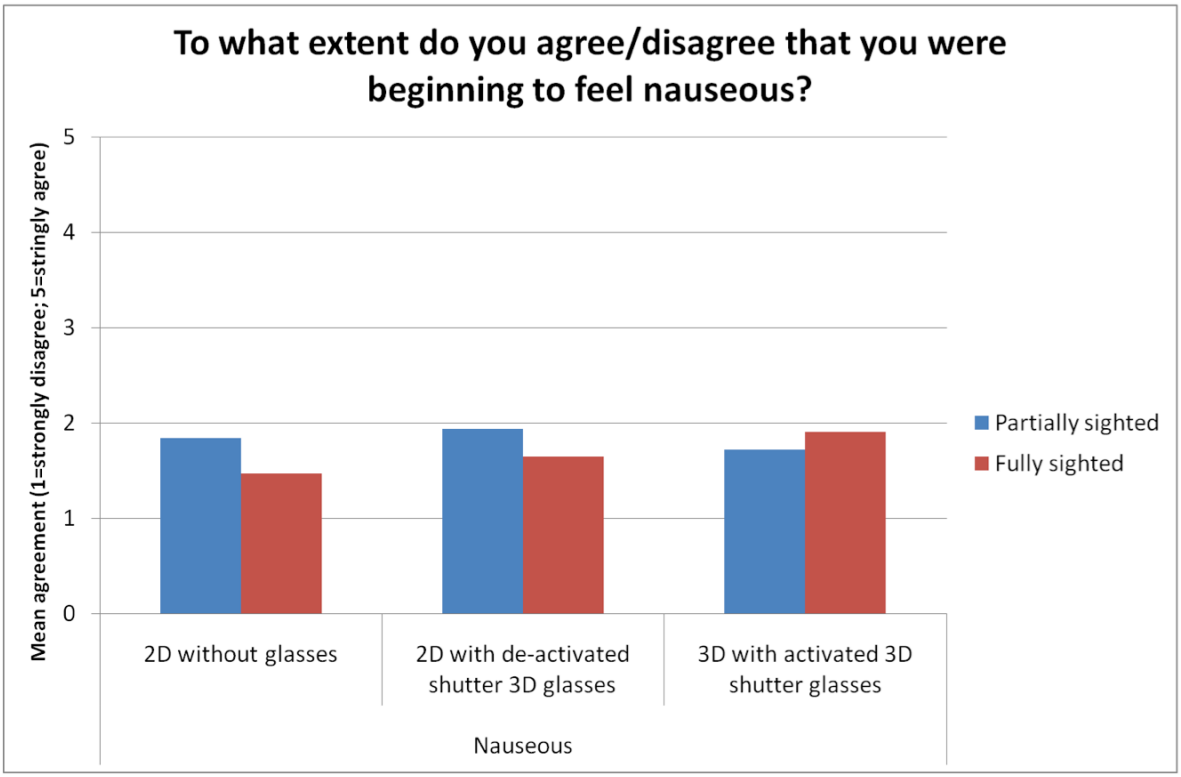

Figure 5d: Mean scores on nausea for the three viewing conditions

3.5.2 Eyestrain

For the statement “I felt that I had (the beginnings of) eyestrain”, there was a significant main effect of viewing condition ($F(2,140) = 7.65$, $p < .05$) but there was no significant main effect of sight condition ($F(1,70) = .376$, ns) and no significant sight condition to viewing condition interaction ($F(2,140) = 1.78$, ns) indicating that the two samples gave similar overall ratings of eyestrain, and their patterns of responding were similar across the three viewing conditions.

To check this result, paired samples t-tests were run on the eyestrain scores from the partially sighted sample. These indicated no significant differences in mean ratings of eyestrain for each paired comparison of viewing condition, namely:

- 3D with activated 3D shutter glasses vs. 2D with de-activated 3D shutter glasses ($t = .39$, ($df = 29$), ns;
- 3D with activated 3D shutter glasses vs. 2D without glasses: $t = 1.22$ ($df = 29$), ns);
- 2D with de-activated 3D shutter glasses vs. 2D without glasses ($t = .57$; ($df = 29$), ns).

This suggests that the significant main effect of viewing condition identified in the ANOVA results were largely attributable to the fully sighted sample’s data. For the fully sighted sample, 3D viewing generated more eyestrain than either of the 2D viewing conditions, even for the relatively short stimulus duration. For the partially sighted sample, 3D viewing did not increase eyestrain relative to 2D viewing. It is logical that such negative effects would only affect people who are able to focus and converge their two eyes – something the partially sighted participants would have been less likely to be able to do than would the sighted participants.

3.5.3 Headache

Participants were asked to what extent they agreed or disagreed with the statement “I felt I had (the beginnings) of a headache”. The analysis revealed a significant main effect of viewing condition ($F(2,146) = 5.20$, $p < .05$) with 2D without glasses yielding the lowest mean rating (1.74), and 3D with activated 3D shutter glasses producing the highest mean rating (2.04). There was no significant difference in overall ratings between the two sight conditions ($F(1,73) = 1.33$, ns), but there was a significant sight condition to viewing condition interaction ($F(2,146) = 5.20$, $p < .05$). The patterns of ratings across the samples and viewing conditions were similar to those identified for ‘dizziness/disorientation’, with stepped increases from 2D to 2D with de-activated glasses and

then to 3D with activated glasses for the sighted sample, and variable results for the partially sighted sample.

The paired t-test results run on only the partially sighted sample's data revealed no significant differences in mean ratings of headache for each paired comparison of viewing condition, namely:

- 3D with activated 3D shutter glasses vs. 2D with de-activated 3D shutter glasses ($t = -.77$, ($df = 31$), ns;
- 3D with activated 3D shutter glasses vs. 2D without glasses: ($t = .00$ ($df = 31$), ns);
- 2D with de-activated 3D shutter glasses vs. 2D without glasses ($t = .72$; ($df = 31$), ns).

This suggests that the significant main effect of viewing condition identified in the ANOVA results was largely attributable to the fully sighted sample's data. For the partially sighted sample, the 3D with activated 3D shutter glasses viewing condition did not increase reports of headache relative to the 2D viewing conditions with or without 3D shutter glasses that had been de-activated. But for the fully sighted sample, 3D viewing generated more headache than either of the 2D viewing conditions, even for the relatively short stimulus duration.

3.5.4 Nausea

For the statement, "I felt (I was starting to feel) nauseous", there was no significant difference in scores between the three viewing conditions ($F(2,146) = 2.17$, ns) nor between the ratings from each of the two sight conditions ($F(1,73) = 1.46$, ns). However, there was a significant sight condition to viewing condition interaction ($F(2,146) = 6.70$, $p < .05$) which described a similar pattern of results found for 'eyestrain', 'headache' and dizziness/disorientation' reported above.

Paired t-tests run on the partially sighted sample's data revealed that nausea ratings for the 2D with de-activated 3D shutter glasses viewing condition were significantly higher (mean 1.94; SD = .56) than those given for the 3D with activated 3D shutter glasses viewing condition (mean 1.72; SD = .46). No other paired comparisons were significant. The patterns of ratings of nausea across the samples and viewing conditions were similar to those identified for other negative effects, with stepped increases from 2D to 2D with de-activated glasses and then to 3D with activated glasses for the sighted sample, and variable results for the partially sighted sample.

3.6 Were the 3D glasses comfortable? Did they interfere with the way in which partially sighted people normally watch TV?

Results summary: Neither the sighted nor partially sighted samples reported wearing the 3D glasses to be uncomfortable. The same result was found in relation to participants' ratings of the extent to which they thought 3D glasses might interfere with how they normally watch TV. It is important to note that this generally positive response to the 3D glasses was obtained in relation to the relatively short viewing periods (four minutes) used in the current study. That said, it was obtained both in response to viewing condition in which the 3D glasses were active, and in which they were worn but de-activated.

At the end of the study, once participants had experienced each of the three viewing conditions, participants were asked about their experience of wearing the 3D glasses, irrespective of whether they had been activated or de-activated. Participants were asked two questions to which they were required to indicate on a 5 point scale their extent of agreement/disagreement ("The 3D glasses were comfortable"; "Wearing the 3D glasses interfered with the way(s) I usually watch TV").

3.6.1 "The 3D glasses were comfortable"

Overall, all participants tended towards agreeing that the glasses were comfortable, and there was no significant impact of viewing condition on these ratings ($F(1,71) = .07$, ns). Indeed, for the partially sighted sample, the mean comfort ratings were identical for both 2D with de-activated 3D shutter glasses and 3D with activated 3D shutter glasses viewing conditions (mean = 3.68). The partially sighted participants gave higher comfort ratings than did fully sighted participants in both viewing conditions in which the 3D glasses were worn i.e. 2D with de-activated 3D shutter glasses and 3D with activated 3D shutter glasses. However, there was no significant difference in comfort ratings between partially and fully sighted participants ($F(1,71) = 1.24$, ns). Furthermore, there was no significant sight condition to viewing condition interaction ($F(1,71) = .07$, ns).

3.6.2 "Wearing the 3D glasses interfered with the way(s) I usually watch TV"

Participants from both the partially sighted and sighted sample tended to report that the wearing 3D glasses would not interfere with normal TV viewing. Furthermore, there was no main effect of viewing condition in this regard ($F(1,69) = .21$, $p > .05$). Whilst the sighted sample was

marginally more likely to agree that wearing 3D glasses would interfere with their normal TV viewing, the difference between the two samples was not significant (F(1,69) = 1.33, ns). In addition, there was no sight condition to viewing condition interaction: the same pattern of results held across both viewing condition and sight condition. It is important to note that this result was found in relation to the relatively short viewing time (four minutes) used. Whether the result would be found for longer viewing durations remains an empirical question.

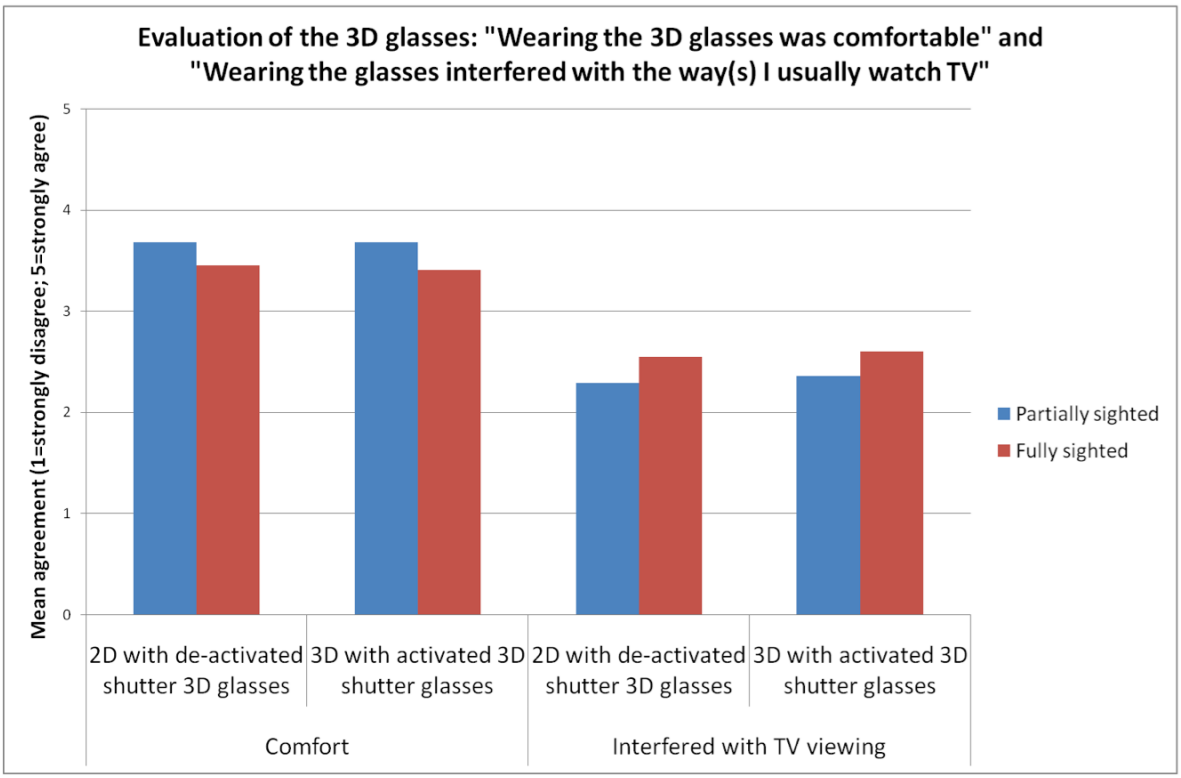

Figure 6: Mean ratings of impact of wearing the 3D glasses

3.7 Could partially sighted people discriminate 3DTV from 2DTV?

Results summary: Nearly all participants in the sighted sample were able to correctly identify the 3D with activated 3D shutter glasses viewing condition as 3D and the 2D without glasses condition as 2D. A significantly lower proportion of the partially sighted sample than of the sighted sample correctly identified the 3D condition, although a minority of the partially sighted participants did identify the 3D condition correctly. This suggests that a minority of partially sighted people could be expected to obtain similar experiential benefits to sighted people from 3D relative to 2D TV. This conclusion should be tempered however, by the much lower proportion of partially sighted than sighted participants who were able to correctly identify the 2D with de-activated shutter

glasses condition as 2D. This finding indicates that partially sighted participants' judgements of whether the clips were 2D or 3D were affected by wearing the 3D glasses (activated or not).

At the end of each of the three viewing conditions, participants were asked "Do you think that presentation was 2D (normal TV) or 3D (TV with real depth)".

For the sample as a whole, participants were significantly more likely to report the presentation as being 3D when they were presented with the 3D with activated 3D shutter glasses viewing condition (81.3% made the correct choice; Chi Square = 77.76, (df = 2), $p < .05$) than when they were presented with either of the 2D viewing conditions. Participants were also significantly more likely to be able to identify 2D in both of the 2D viewing conditions (2D with de-activated 3D shutter glasses: Chi Square = 29.04, (df = 2), $p < .05$; 2D without glasses: Chi Square = 86.72, (df = 2), $p < .05$). A greater proportion of the sample made the correct choice when the 2D viewing condition was presented without, rather than with, de-activated 3D shutter glasses (84% correct for 2D without glasses vs. 62.7% correct for "2D with de-activated 3D shutter glasses") (see Table 5).

Table 5: Accuracy of discrimination between 2D and 3D viewing conditions for both samples combined

	Viewing Condition		
Response	**3D**	**2D glasses**	**2D (no glasses)**
3D	81.3%	18.7%	6.7%
2D	9.3%	62.7%	84%
Don't Know	9.3%	18.7%	9.3%

Table 5 presents a summary of all participants' accuracy in determining whether a viewing condition was 2D or 3D, this data is also split by sample.

When presented with the 3D viewing condition, a greater proportion (95%) of the fully sighted compared to the partially sighted sample (62.5%) were able to correctly identify the 3D viewing condition as 3D. The partially sighted sample was more uncertain (21.9% responded "don't know") compared to the fully sighted sample (0% did not know). Chi square analyses for each sample indicated that these skews in frequency were significant (partially sighted: Chi Square = 12.44, (df =

2), $p < .05$; fully sighted Chi Square = 35.37, (df = 1), $p < .05$) (see Figure 7).

For the 2D without glasses viewing condition 75% of the partially sighted sample correctly identified that it was 2D, 9.4% incorrectly thought it was 3D, and 15.6% responded “don’t know”. This skew in responding was significant (Chi Square = 25.19, (df = 2), $p < .05$). For the fully sighted sample, 90.7% correctly identified the 2D without glasses viewing condition as 2D, 4.7% incorrectly identified it as 3D and a similar proportion responded “don’t know”. These observed frequencies were also significantly different from expected frequencies (Chi Square = 63.67; (df = 2); $p < .05$).

Finally, correct identification was lowest for the 2D with de-activated 3D shutter glasses viewing condition for both samples analysed separately. Of the fully sighted group, 74.4% were able to identify correctly the 2D with de-activated 3D shutter glasses presentation as 2D, 16.3% incorrectly thought it was 3D and 9.3% responded “don’t know”. Nevertheless, these frequency differences were significantly different from expected frequencies (Chi Square = 32.98, (df = 2), $p < .05$). The partially sighted group were much less accurate in identifying the “2D with de-activated 3D shutter glasses” viewing condition as 2D. Only 46.9% correctly identified it as 2D, 21.9% thought it was 3D and 31.2% were not sure. These frequencies were not significantly different from chance variation (Chi square = 3.06, (df = 2), ns) (see Figure 7), indicating that the partially sighted sample was not able to correctly identify the 2D with de-activated 3D shutter glasses presentation as 2D.

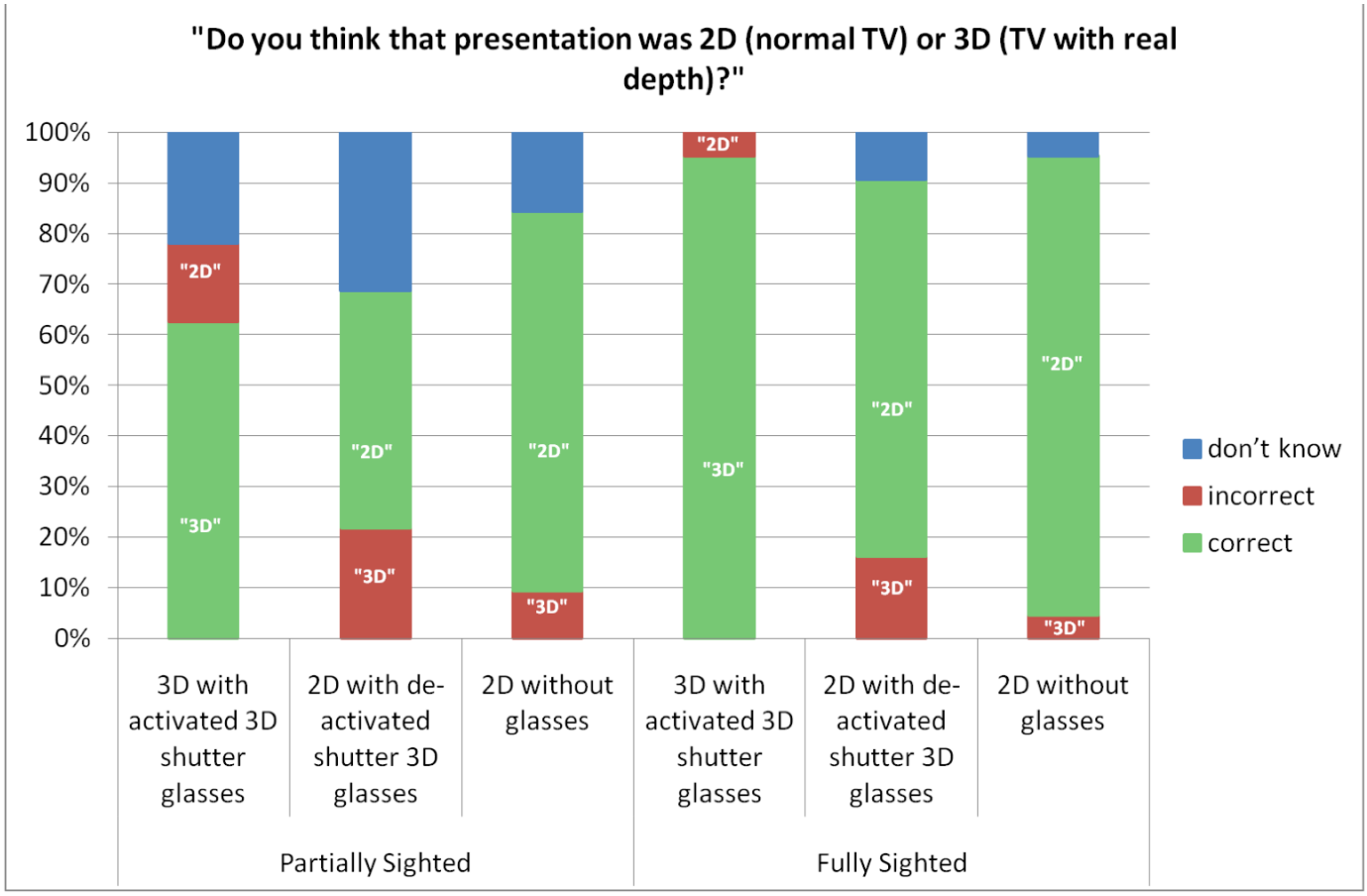

Figure 7: Participants' judgements of whether each presentation was 2D or 3D across viewing condition for the two samples

The sight conditions reported by the 12 partially sighted participants who incorrectly believed they had seen 2D after the 3D presentation, or were unsure of the viewing condition, were explored. That several of these participants had multiple diagnoses and the small cell sizes for any one sight condition make it difficult to draw conclusions from this. However, five of these participants had monocular vision described in various ways, sometimes amongst other conditions, which would explain their inability to perceive stereoscopic displays.

3.8 Did 3DTV provide a better viewing experience than 2DTV for partially sighted people?

Results summary: Whilst more partially sighted participants agreed than disagreed that the 3DTV presentation gave them a better viewing experience than they have at home, the pattern of results was more pronounced and statistically significant for sighted participants.

At the end of the three viewing conditions and after being told which of the viewings was 3D, participants were asked to indicate on a 5-point scale the extent to which they agreed or disagreed with the statement

“The 3DTV viewing condition gave me a better (viewing) experience than I have at home”.

Whilst the partially sighted participants were more likely to agree than disagree with this statement (56% agree/strongly agree vs. 28% disagree/strongly disagree), a Chi square analysis of this data revealed no significant differences in these (observed vs. expected) frequencies for the partially sighted sample (Chi Square = 4.56, (df = 4), ns). This result indicates that the 3DTV viewing condition did not give the partially sighted sample as a whole a significantly better or worse (viewing) experience than they have at home.

When both samples are considered, as shown in Figure 8, the fully sighted participants were more likely than the partially sighted participants to agree that the 3DTV viewing condition provided a better experience: over 90% of the fully sighted sample ‘agreed’ or ‘strongly agreed’, compared with 56% of the partially sighted sample. A one-way ANOVA revealed that the difference in mean scores was significant between the two sight conditions ($F(1,73) = 8.88$, $p < .05$; fully sighted: mean = 4.30; SD = .18; partially sighted: mean = 3.50, SD = .20). Furthermore, Chi square analysis of the frequency data for the fully sighted sample revealed a significant difference in the (observed vs. expected) frequencies ratings (Chi Square = 29.84, (df = 3), $p <0.05$). Thus in contrast to the results from the partially sighted sample, fully sighted participants reported benefitting from the 3D presentation compared with what they experience at home.

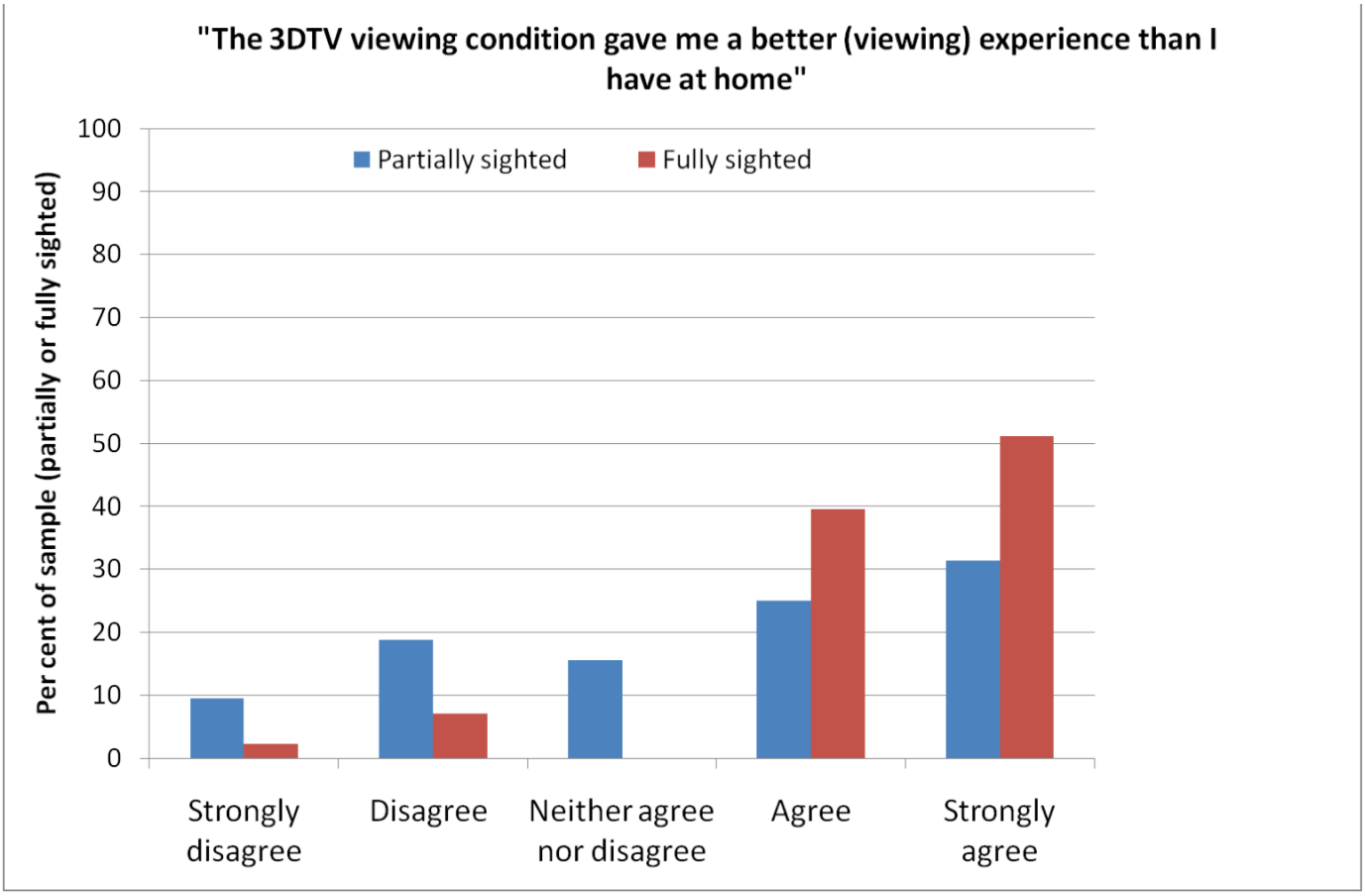

Figure 8: Responses by sight level: "3D gives me a better experience than I have at home"

3.9 Would partially sighted people be at a disadvantage if 3DTV was the only TV available?

Results summary: Neither the sighted nor partially sighted samples agreed particularly strongly that they would be at a disadvantage relative to now, if 3DTV was the only TV available. In fact, there was a slight tendency for the sighted sample to agree more than the partially sighted sample with the statement.

At the end of the three trials and once they were made aware of the trial in which they had viewed 3D, participants were asked to indicate on a 5-point scale the extent to which they agreed or disagreed with the statement "I would be disadvantaged relative to now if 3DTV was the only TV available".

The partially sighted participants were more likely to disagree than agree with this statement (64.5% disagree/strongly disagree vs. 25.8%

agree/strongly agree). A Chi-square analysis revealed that the (observed vs. expected) frequencies were significantly different (Chi-square = 19.48, (df = 4), $p < 0.05$). Thus, in relation to the viewing durations used in this study, partially sighted participants did not perceive themselves to be disadvantaged by 3D.

The partially sighted sample was compared with fully sighted sample on this measure. As shown in Figure 9, there was less skew towards disagree for the fully sighted sample, compared to the partially sighted sample. In fact a greater proportion of fully sighted than partially sighted participants agreed that they would be at a disadvantage if 3DTV was the only TV available (35.7% of the fully sighted sample compared with 25.8% of the partially sighted sample). A one-way ANOVA revealed no significant difference in the mean scores (partially sighted: mean = 2.61, SD = .23; fully sighted: mean = 2.88, SD = .20) between the two samples ($F(1,72) = .76$, ns). Chi square analysis of the frequency data for the fully sighted sample revealed no significant difference in the (observed vs. expected) frequencies ratings (Chi Square = 2.52, (df = 4), ns).

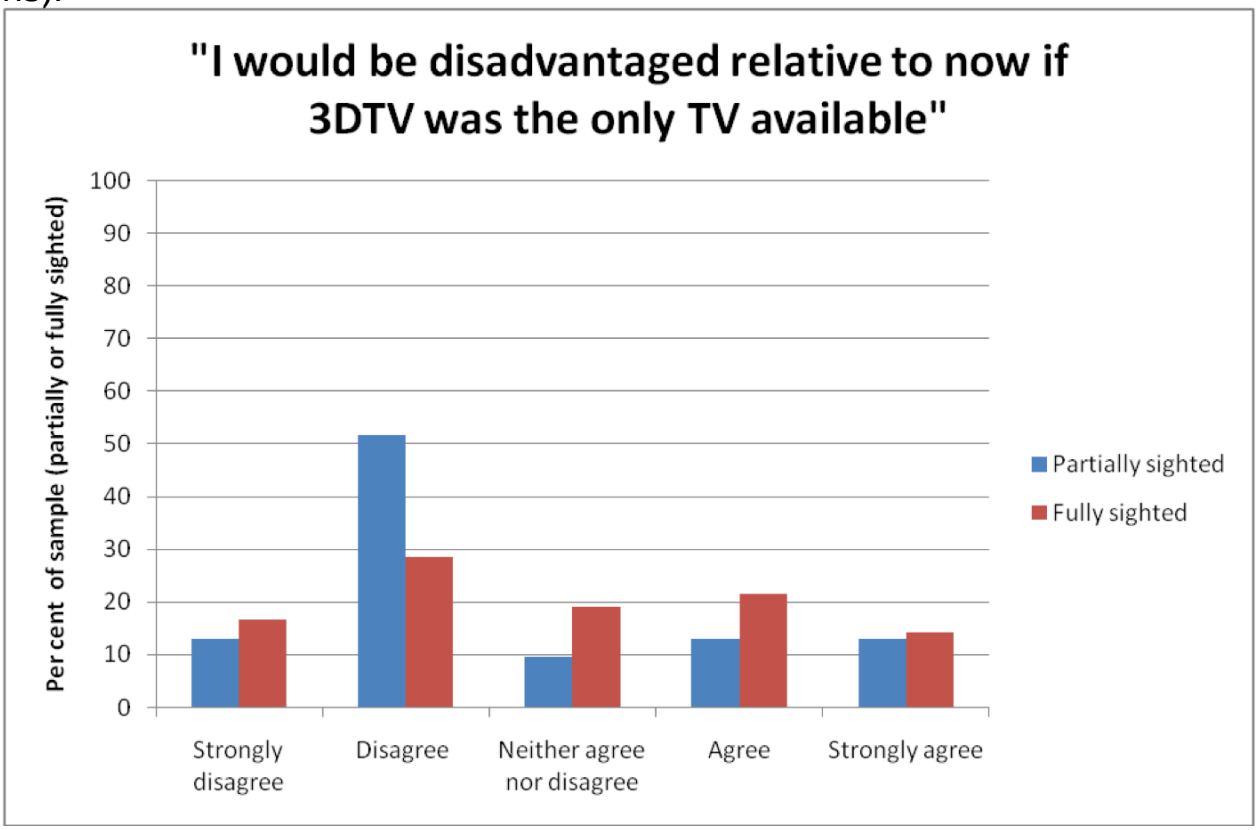

Figure 9: Responses by sight level: "I would be disadvantaged if only 3D was available"

3.10 Could partially sighted people see more or less when watching 3D presentations than when they watched 2D presentations?

Results summary: Neither the sighted nor partially sighted samples agreed particularly strongly that they could see less/make out less in the 3DTV presentation than when they usually watch TV. In fact, there was a slight, though not significant, tendency for the sighted sample to agree more than the partially sighted sample with the sentiment. The question was asked in two ways:

- "I could make out less in 3DTV than I usually can"; and
- "I could see more when I was watching the 3D presentation than when I was watching the regular (2D) TV".

Responses to both questions were consistent.

At the end of the three viewing conditions and once participants were made aware of which clip was in 3D, they were asked to indicate on a 5-point scale the extent to which they agreed or disagreed with the statements:

- "I could make out a lot less in the 3DTV presentations than I usually can when I watch TV"; and
- "Thinking of what I could see on screen, I could see more when I was watching the 3D presentation than when I was watching the regular (2D) TV".

As the two questions are semantically similar, the relationship between all responses (both samples combined) to the two questions was explored using Pearsons r correlation. A weak but significant inverse correlation was revealed ($r = -0.27$, $p < 0.05$, $n = 74$). The two questions are considered separately in the following sections.

3.10.1 "I could make out a lot less in the 3DTV presentations than I usually can when I watch TV"

The partially sighted sample were more likely to disagree than agree that they could make out less in the 3DTV presentations (87.5% disagree/strongly disagree vs. 6.3% agree). A Chi square analysis indicated a highly significant difference in the (observed vs. expected) frequencies for this question item (Chi Square = 38.3, (df = 3), $p < 0.05$). Thus partially sighted participants did not feel they could make out less in the 3D presentation.

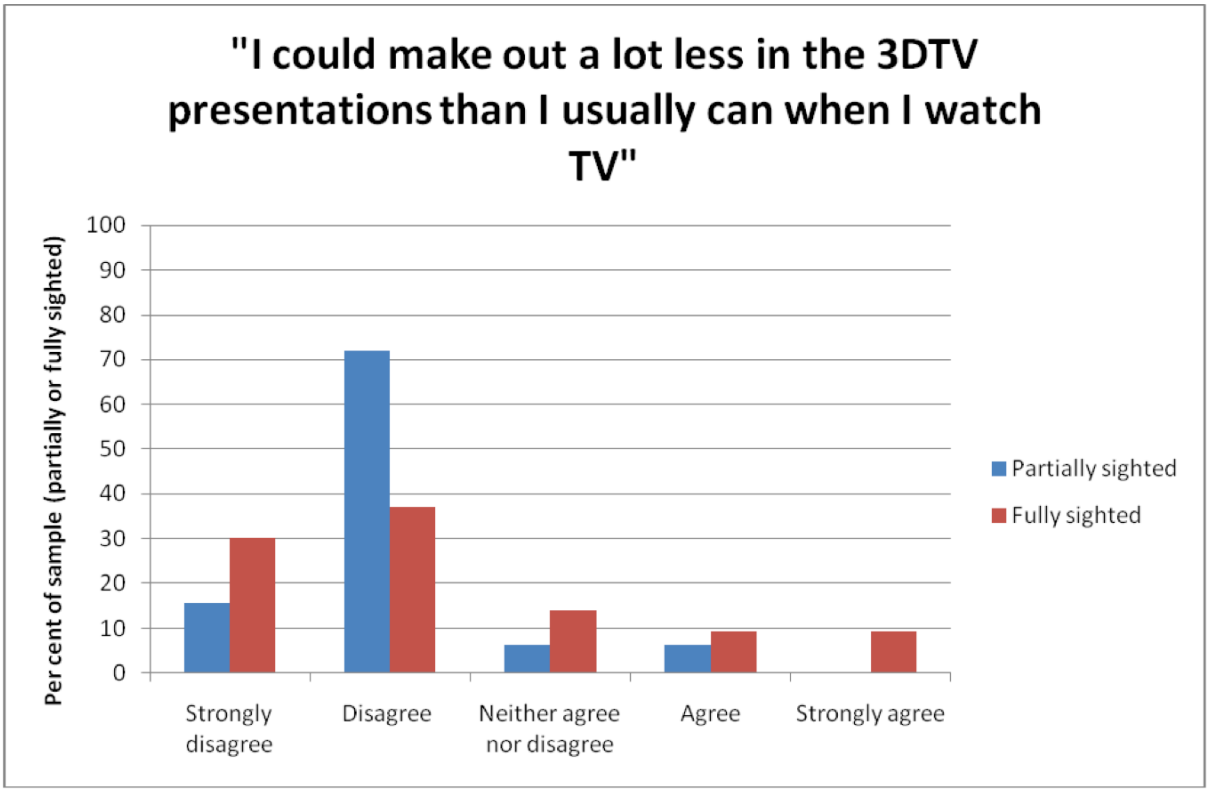

Figure 10: Responses by sight level: "I could make out a lot less in 3D than usual TV"

The partially sighted sample was compared to the fully sighted sample. As shown in Figure 10 and similar to the results presented in Figure 9, there was less skew towards disagree for the fully sighted, compared to the partially sighted sample. In fact, a greater proportion of the fully sighted than partially sighted sample agreed that they could make out less in the 3DTV presentations (fully sighted: 18.6% vs. partially sighted: 6.3%). However, the difference in mean agreement scores (partially sighted: mean = 2.03; SD = 0.7; fully sighted: mean = 2.30; SD = 1.26) between the two sight conditions was not significant ($F(1,74) = .1.2$, ns). Chi square analysis of the frequency data for the fully sighted sample revealed a significant difference in the (observed vs. expected) frequencies ratings (Chi Square = 14.33, (df = 4), $p < 0.05$). Thus, the fully sighted participants also did not feel they could make out less in the 3D presentation.

3.10.2 "Thinking of what I could see on screen, I could see more when I was watching the 3D presentation than when I was watching the regular 2D TV"

A slightly larger proportion of the partially sighted sample agreed rather than disagreed that they could see more in 3D (46.9% agree/strongly agree vs. 37.5% disagree/strongly disagree) but the difference in these

proportions was not statistically significant (ns) (Chi Square = 5.5, (df = 4), ns).

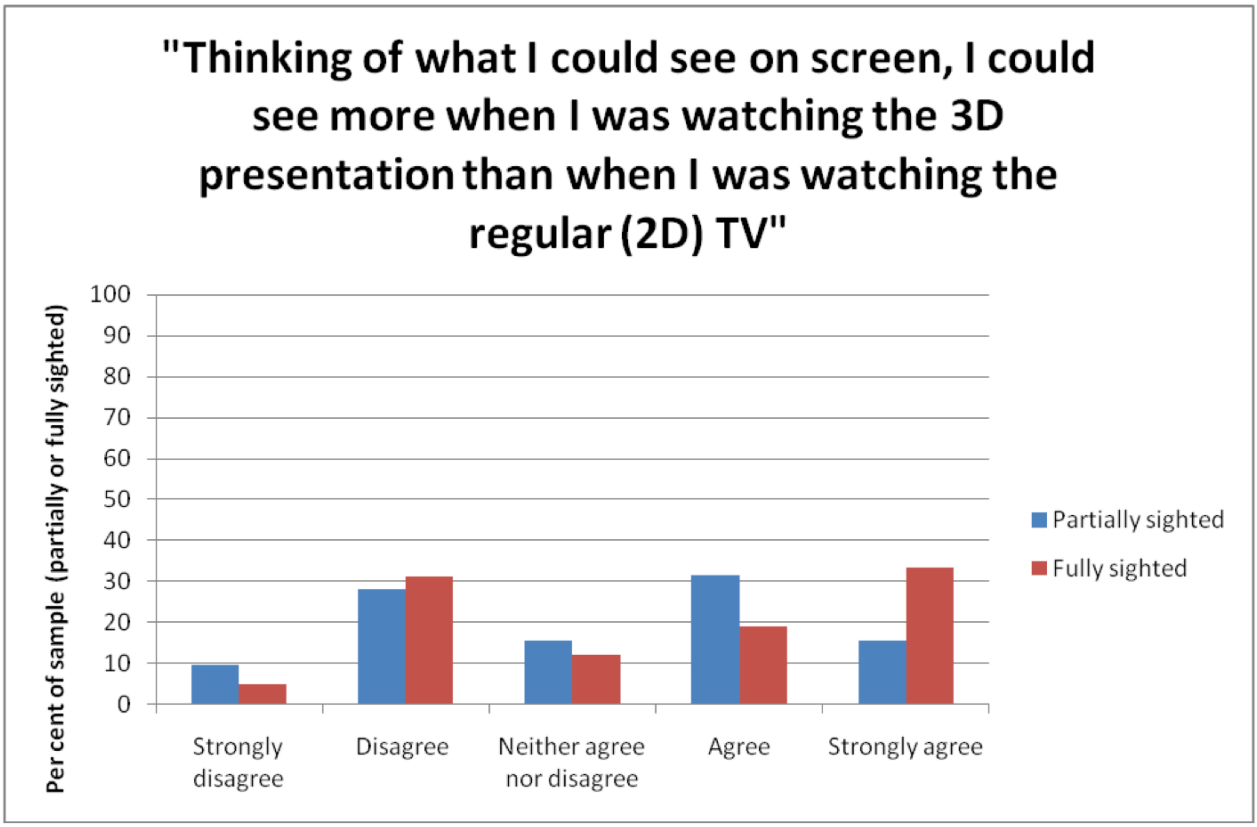

Figure 11: Responses by sight level: "I can see more in 3D than usual TV"

As shown in Figure 11, a greater proportion of the fully sighted sample agreed that they could see more when watching 3D (fully sighted: 52.3% vs. partially sighted: 46.9%), though similar proportions disagreed (fully sighted: 35.8% vs. partially sighted: 37.5%). The difference in mean scores between the two sight condition samples (partially sighted: mean = 3.16, SD = .23; fully sighted: mean = 3.45, SD = .21 was not significant ($F(1,73) = .91$, ns). A Chi Square analysis of this data for only the fully sighted sample, revealed a significant difference from expected values (Chi Square = 12.52, (df = 4), $p < 0.05$). The 'U' shape distribution of the fully sighted participants' scores suggests that opinion was split among the sample.

3.11 Which aspects, if any, of 3DTV are preferred by partially sighted people and which aspects, if any, are disliked?

Throughout the study, qualitative comments were elicited on several occasions from participants about what they liked and disliked about the three viewing conditions. At the end of each viewing condition they were

asked “Was there anything you liked or disliked about that experience, and why?” and “Would you say that viewing experience was better or worse than when you watch TV at home and why?”. At the end of the three viewing conditions they were asked, “If you were trying to persuade someone to get a new 3DTV system based on your experiences today, what aspects of the system or experience would you emphasise and why?” and “If you were trying to dissuade someone from getting a new 3DTV system based on your experiences today, what aspects of the system or experience would you emphasise and why?”

3.11.1 Positive comments

Partially sighted participants’ comments on the 3D presentation before they were told that it was 3D suggested that some, but not all, noticed that the presentation was:

More vivid:
“It was really vivid, I almost dodged the ball”

Sharper and clearer; with more colour contrast
“sharp, clear picture quality, colour contrast”
“lots of contrast”

A more dynamic presentation, with better depth:
“slightly better, more 3D”
“seeing that depth of field; more perspective”.

One participant commented on the novelty of the experience:
“So much better, just for the sheer surprisingness [sic] of the 3D. Quality better than HD”.

Another participant commented that improvements in perceived picture quality positively influenced their perceptions of audio quality, though of course this could simply have been reflecting that the equipment in the i2 lab was of better quality than the equipment the participant had at home:
“more surround sound”

When the 3D presentation was revealed to participants at the end of the three viewing conditions, they were asked how they might persuade someone to get a new 3DTV system. The following comments are illustrative of their views and tend to emphasise a sense of presence/engagement and the clarity/contrast of the picture:

“Be part of the movie, very real”

“Everything for the sheer look on their face as they try to dodge the flying objects”

“I would emphasise the fact that the picture is bold”

“I would suggest to watch the 3DTV in the dark”

“More involved in the film, drawn into the greater depth, glasses made a difference to viewing, more pleasurable viewing experience.”

“Sense of being within the film”

3.11.2 Negative

Before they were aware of the viewing condition, a minority of partially sighted participants gave some negative comments on the 3D presentation. These related to the experiences of:

Eyestrain

- “Disliked eyestrain – still have it now”; and

The glasses:

- “Shape of the glasses (frame) could be bigger and thinner”;
- “The glasses take out light from the TV and this is a bad thing because light enables me to see more clearly”.

After they had been informed which of the viewing conditions was 3D, participants were asked what they would say to dissuade someone from getting a 3DTV system. Their comments centred on the glasses, eyestrain and whether the benefits of a 3DTV system would be worth the cost.

“eyestrain and general discomfort in the visual area.”

“Greater depth of field doesn't give much for extra cost, such a small difference, too much money. Not quite the subtlety of vision to detect.”

“I would emphasise the fact that you have to wear the glasses which might interfere with how much light you can get.”

“I wouldn't say don't try it, but maybe to try it at the cinemas first.”

“Not a lot of material in 3D, glasses not comfortable”

“When you are using the 3DTV without the glasses, the 3D becomes redundant.”

3.11.3 Neutral

Some comments from the partially sighted sample indicated that some participants did not notice the difference.
“It seemed very normal, nothing that I liked or disliked”

“Same as watching a normal film”

“No difference in depth”

4 Summary of results

Here we summarise the findings of this research in relation to the research questions addressed by the study.

Do partially sighted people prefer 3DTV to 2DTV?

Whilst a minority of participants made some negative comments about their experiences of the 3D presentation, overall 3D was the preferred viewing condition. Whilst this difference in preference was significant for the fully sighted sample, it failed to reach significance for the partially sighted sample.

Half of the partially sighted sample preferred 3D with activated 3D shutter glasses to 2D with or without 3D shutter glasses that had been de-activated. This skew in preference, however, was not significant. A number of the partially sighted participants who instead preferred either of the 2D viewing conditions with or without 3D shutter glasses that had been de-activated were found to have conditions which would render the depth effects within the 3D presentation, such as a ball bouncing out of the screen, or an object appearing to recede into the screen, imperceptible - i.e. it would appear as 2D and thus identical to the other two conditions. In contrast, the fully sighted sample showed a significant preference for the 3D with activated 3D shutter glasses viewing condition

Do partially sighted participants report any perceived differences in picture quality between 3D and 2D TV?

Partially sighted people reported subtle differences in picture quality across the three viewing conditions. On average, they reported significantly better picture quality for 3D with activated 3D shutter glasses than 2D without glasses. In addition, simply wearing the de-activated shutter glasses improved some partially sighted participants' perceptions of the picture quality of the 2D clip. Whilst a small minority of partially sighted participants referred to the glasses reducing perceived glare from the screen, the finding could be evidence of an effect of expectation, for example participants reported picture quality to be better just because they were wearing glasses and knew they were taking part in a study on 3DTV. Picture quality ratings were not related to level of sight loss or to whether their sight loss was congenital or acquired. Partially sighted people's ratings of picture quality were similar to those found in the fully sighted sample.

What is partially sighted participants' sense of engagement in 3D scenes relative to 2D scenes?

Partially sighted people reported significantly higher engagement/presence for 3D with activated 3D shutter glasses than either of the 2D viewing conditions with or without 3D shutter glasses that had been de-activated. Engagement and presence ratings were not related to level of sight loss or to whether their sight loss was congenital or acquired. Whilst the pattern of partially sighted people's ratings of engagement/presence was similar to that found in the fully sighted sample, fully sighted participants reported even higher engagement/presence ratings for the 3D with activated 3D shutter glasses viewing condition.

Would partially sighted people recommend the 3DTV viewing experience to their friends?

Whilst participants from both samples tended to agree they would be more likely to recommend the 3D experience to their friends than either of the other viewing conditions, this difference was only significant for the fully sighted participants.

Were any negative effects reported, specifically disorientation, eye strain, nausea and headache, as a result of viewing 3DTV?

Reported incidence of negative effects (dizziness/disorientation, eyestrain, headache and nausea) was low: most participants disagreed that they experienced any negative effects. For the partially sighted sample, 3D did not significantly increase any negative effects relative to the 2D conditions. In fact, the only significant effect was for viewing condition, '2D with de-activated 3D glasses' which significantly increased nausea ratings relative to ratings from the 3D viewing condition. However it is important to bear in mind that the study only measured negative effects in relation to a relatively short exposure to four minute 3D film clips.

Were the 3D glasses comfortable and did wearing them interfere with the way(s) in which partially sighted people normally watched TV?

Evaluations of the 3D glasses were generally positive. Participants in both samples tended to report that the 3D glasses were comfortable and did not interfere with the way they usually watch TV – regardless of whether they needed to wear the 3D glasses on top of their own

corrective lenses. The partially sighted sample gave non-significantly more positive ratings of the glasses than did the fully sighted participants, irrespective of whether they wore them in the 2D or 3D conditions. In relation to this finding, it is important to note that participants were only required to wear the glasses for short durations of four minutes at a time. Whether these positive evaluations would be obtained in relation to longer viewing times, for example the duration of a television programme or a film, remains an empirical question.

Can partially sighted people discriminate 3DTV from 2DTV?

Participants' ability to discriminate between the 2D and 3D presentations was good although better for the fully, compared with partially, sighted sample. Participants in both samples made more errors in the "2D with de-activated 3D shutter glasses" viewing condition - which less than half of the partially sighted sample correctly identified as 2D. That a minority of the partially sighted participants did identify the 3D condition correctly suggests that a minority of partially sighted people could be expected to obtain similar experiential benefits to sighted people from 3D relative to 2D TV

Almost half of the partially sighted participants who showed poor ability to discriminate 3D from 2D had been diagnosed with a condition that rendered them with monocular vision; thus their inability to discriminate 3D was not surprising. There was not a sufficient number of cases with particular sight loss diagnoses to draw conclusions about which specific diagnosable sight conditions may lessen the experiential benefits of 3DTV viewing.

Does 3DTV provide a better viewing experience for partially sighted people than 2DTV?

On the whole, partially sighted participants were more likely to agree than disagree that 3DTV provides a better viewing experience than does 2DTV, though not to the same extent as did sighted participants. This was not the case for all the partially sighted participants in the study sample, a minority of whom made some negative comments about aspects of the 3DTV experience which focused on eye strain and the glasses.

Do partially sighted people consider that they would be at a disadvantage if 3DTV was the only TV available?

Partially sighted participants did not perceive themselves to be disadvantaged if 3DTV was the only TV available. The perceptions of partially sighted participants with respect to this question were more positive than those of sighted participants, who perceived more disadvantages from 3DTV.

Could partially sighted people see more or less when watching 3D presentations than when they watched 2D presentations?

Most partially sighted participants generally disagreed that they could see less when watching the 3D presentations than when they watch TV at home. Opinion was more divided in relation to whether 3D helped them to see more – responses to this question were split.

Which aspects, if any, of 3DTV are preferred by partially sighted people and which aspects, if any, are disliked.

Without awareness that they had viewed 3DTV partially sighted participants commented on the viewing experience being more vivid, sharp, clear and dynamic with more contrast and depth. At the end of the experience, partially sighted participants highlighted their perceptions of the enhanced sense of presence (involvement/engagement) and improved clarity/contrast as key benefits of 3DTV.

Negative comments focused on eyestrain, the design of the glasses, the glasses reducing the light and the low cost-benefit of the experience.

5 Future work

Whilst the authors have strong confidence in the results presented here, the study was of course of limited scope. The results reported here are broadly positive and do not in themselves suggest strong concern about potential negative effects for partially sighted people from viewing 3DTV for short periods of time. However, by definition, the study did not address the risk of potential negative effects of 3DTV for partially sighted people over longer viewing durations, nor can it claim to be comprehensive given the relatively small sample employed.

It is therefore i2's recommendation that further research be conducted in this area to explore the following issues in more depth:

- Desk and expert research to identify sight conditions which might be expected to be associated with problems or discomfort with viewing 3DTV;
- Research using larger sample sizes, with partially sighted people affected by the conditions identified above.
- Research involving longer viewing times, and a longitudinal view, to establish whether negative effects/discomfort develop over time.
- Exploration of interactions between the positive and negative effects of 3D presentation and the novelty of 3DTV to participants.

6 List of appendices

6.1 Consent Form

Title of Project: Evaluation of 3D display (July 2010)
Researchers: i2 media research (Jonathan Freeman, Andrea Miotto, Eva Ferrari, Phil Dumbreck)

Thank you for agreeing to take part in this research about 3D television. You will be asked some background questions and then you'll be watching three, two to five minute video clips and answering some questions on each. You'll need to bring any corrective eye-wear (e.g., glasses, contact lenses, other aids) that you would normally use whilst watching TV, otherwise unfortunately you will not be able to take part.
Please note:

- You are free to withdraw your participation in the study at any time and without penalty.
- You are free to not answer any particular question you are asked without giving a reason and without penalty.
- If you have any questions, please ask the researcher before you complete this form.
- If you still agree to participate, please indicate in the third column of table after each statement, and print, sign and date the sections below:

1	I confirm that I have read and understood the information given for this research and have had the opportunity to ask questions.	
2	Having read the information, I consent to take part in this research session.	
3	[I agree to have my participation in the research described above, audio recorded.]	
4	[I agree to have my participation in the research described above, video recorded.]	

Name of Participant:
Date:

Signature:

6.2 Background Information

SECTION 1: Background Information

1. Would you say you use any vision at all for watching TV?

- No [END]
- Yes [CONT]

2. Do you have photo-sensitive epilepsy?

- Yes [END]
- No [CONT]
- Don't know [Ask 3]

3. Have you ever had a seizure (fit)?

- Yes [END]
- No [CONT]

4. When you currently watch or follow a programme or film on DVD or on television do you use any of the following? [multicode]

- Use your residual sight to watch
- Wear special stronger glasses
- Get closer to the TV screen
- Use a magnifier
- Adjust the screen settings
- Adjust the lighting in the room
- Use a large screen TV
- Ask my friends or family members to assist me by explaining what happens on the screen
- Just try to pick up as much as I can from the sound of the film or Programme
- Use audio description to explain to me what happens on the screen

Make none of these adjustments

- Never watch TV or DVD(s)
- Other

5. Do you have with you right now any glasses or aids you usually use to watch TV?

- No [END]
- Yes [CONT]
- I don't use glasses/aids [CONT]

6. What is your age (band)?

- Prefer not to say
- 18-24 years
- 25-34 years
- 35-44 years
- 45-54 years
- 55-64 years
- 65-74 years
- 75-84 years
- 85 years and above

7. What is your sex?

- Male
- Female

8. Which of the following best describes what you are able to see? [select ONE]

- Prefer not to answer
- [No light perception [END]
- In a room during daytime, you can tell by the light where the windows are
- Shapes of the furniture in a room
- Recognise a friend if you get close to his or her face
- Recognise a friend who is at arms length away
- Recognise a friend across the room
- Recognise a friend across the road
- Everything

8. What sight conditions have you been diagnosed with, if any? [free response]

9. [If applicable] Were you born with your sight condition or did it develop? [select ONE]

- Born with it
- Acquired/Developed
- [Note how long ago, if developed, comm.]:

10. Approximately how many hours of TV do you watch each week? [select one]

- 0-8 hours
- 9-16 hours
- 17-24 hours
- 25-32 hours
- 33-40 hours
- 41 hours or more

11. Have you seen 3D films at the cinema or on television before (e.g. IMAX 3D, 3DTV)? [select one]

- Yes, several times
- Yes, once or twice
- No, never
- Don’t Know

SECTION 2a: Evaluation 1 – 2 – 3 (rep * 3)

(2D on 2DTV, 2D on 3DTV, 3D on 3DTV)

1. Do you think that presentation was 2D (normal TV) or 3D (TV with real depth)?

[Researcher to circle the correct condition, after the respondent has replied]

- 2D
- 3D
- Don't know

2. How would you rate the quality of the picture?

- Excellent
- Good
- Acceptable
- Poor
- Very poor
- Don't know

How much do you agree or disagree with the following statements.

3. I had a sense of being in the scenes displayed

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree
- Don't know

4. I'd recommend the experience to my friends

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree
- Don't know

5. I felt (was beginning to feel) dizzy and disorientated

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree
- Don’t know

6. I felt that I had (the beginnings of) eyestrain

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree
- Don’t know

7. I felt I had (the beginnings of) a headache

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree
- Don’t know

8. I felt (was starting to feel) nauseous

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree
- Don’t know

9. [If applicable] The 3D glasses were comfortable

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree
- Don’t know

10. [If applicable] Wearing the 3D glasses interfered with the way(s) I usually watch TV

- Strongly agree
- Agre
- Neither agree or disagree
- Disagree
- Strongly disagree
- Don't know

Open ended questions:

To be asked after each viewing:

Viewing 1 [**note condition:**]

1. Was there anything you liked or disliked about that experience, and why?

2. Would you say that viewing experience was better or worse than when you watch TV at home, and why?

6.3 Post-viewing Evaluation

To be asked after all 3 viewings:

1. The 3DTV gave me a better (viewing) experience than I have at home

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree
- Don’t know

2. I would be disadvantaged relative to now if 3DTV was the only TV available

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree
- Don’t know

3. I could make out a lot less in the 3DTV presentations than I usually can when I watch TV

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree
- Don’t know

4. Thinking of what I could see on screen, I could see more when I was watching the 3D presentation than when I was watching the regular (2D) TV

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree
- Don’t know

5. Which of the 3 viewing conditions did you like most, and why?

6. If you were trying to persuade someone to get a new 3DTV system, based on your experiences today what aspects of the system or experience would you emphasise, and why?

7. If you were trying to dissuade someone from getting a new 3DTV system, based on your experiences today what aspects of the system or experience would you emphasise, and why?

And finally:

Are you willing to be re-contacted for further research for RNIB?
[If yes, name & contact]

Name:
Contact:

Are you willing for us to pass your contact details to RNIB for them to contact you to invite you to participate in further research?
Yes
No

6.4 Debrief

Post-discussion information sheet

Project: Evaluation of 3D display (July 2010)

Thank you for taking part in this research. We hope you have enjoyed the session. The work was conducted by i2 media research limited for RNIB.

The main aims of this research were to explore benefits and drawbacks for partially sighted people (who self report having useful vision for watching TV) from 3D relative to 2D television.

If taking part in the research has raised any issues for you or has left you with any questions or concerns that you would like to discuss further with us, feel free to get in contact with the project researchers, using the contact information below.

If you prefer to get in contact by phone, please call Jonathan Freeman. You can reach Jonathan on 020 7919 7884. If you prefer to get in contact by email, please email: J.Freeman@gold.ac.uk

Thank you.

ISBN: 978-1-4445-0076-9

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