

Beyond Blur: Real-time Ventral Metamers for Foveated Displays

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1 USER STUDY

This supplemental document provides additional details and larger figures for the perceptual experiments and results from Section 6 in the main article. The participant information sheets have also been included in the Appendix.

1.1 Performance Study

Figure 1 shows a full resolution plot of the responses and fitted logistic models (per condition). Table 1 shows all the terms of the model used in the significance tests.

	Estimate	SE	T-Statistic	p-Value
Intercept	3.033627	0.140241	21.63151	<0.0001
Eccentricity	-0.10433	0.005709	-18.276	<0.0001
Blur 0.35	0.105042	0.138251	0.759789	0.44738
Blur 0.7	-0.39177	0.131129	-2.98768	0.002811
Blur 1.05	-0.61184	0.129119	-4.73861	<0.0001
Blur 1.4	-0.84645	0.127641	-6.63147	<0.0001
Ours	0.258257	0.141292	1.827822	0.067576

Table 1. Coefficients of the Generalised Linear Model fit to the Performance Study results.

14 participants volunteered for this study each making 300 observations. All conditions (eccentricity and method) were balanced. The model was therefore fit to 4200 observations. It had a χ^2 statistic (vs. the constant model) of 482.

Equation 1 is the model used to draw the fit lines in Figure 1. It is a linear model with a logit link function [1].

$$p = \frac{1}{1 + e^{-(\text{Intercept} + \text{Eccentricity} \cdot e + \text{Method})}} \quad (1)$$

Where *Eccentricity* is the Eccentricity estimate in Table 1, *e* is the eccentricity of the condition and *Method* is the Estimate of the mode in Table 1 (BLUR 0.35, BLUR 0.7, BLUR 1.05, BLUR 1.4, OURS).

1.2 Preference Study

Table 2 shows the results of the preference study. 10 participants volunteered each making 252 choices. All conditions were balanced. The number of times they chose method A over method B is indicated, along with the results of a binomial test comparing to chance. The test was two-sided with equal counts.

Figures 2 & 3 show example stimuli as seen by the participants at full resolution. Two scenes are shown, CONSTRUCTION and GALLERY. There were seven scenes in total (including the above). Every participant saw all scenes.

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Method A	Method B	Trials	Successes	P	p-value
Ours	F&S	420	343	0.816667	<0.0001
Ours	Blur	420	184	0.438095	0.012734
Reference	Ours	420	302	0.719048	<0.0001
Reference	Blur	420	282	0.671429	<0.0001
Reference	F&S	420	374	0.890476	<0.0001
F&S	Blur	420	72	0.171429	<0.0001

Table 2. Results of the preference study; success in this case indicates choosing Method A over Method B. P is successes / trials.

1.3 Detection Study

Table 3 shows the full results of the Detection Study. 10 Participants made 294 choices each. The number of consistent and inconsistent images were balanced within each condition, and there were an equal number of trials for each condition, except for REFERENCE, which could not be inconsistent. The success p-value is the result of a binomial test comparing the number of times an image was successfully classified to chance. The bias p-value is the result of a binomial test comparing the Consistent/Inconsistent distribution to chance. The binomial tests were two-tailed with equal counts.

Figure 4 shows an example set of consistent and inconsistent images. Participants would see each image, for each scene, an equal number of times, in addition to the control (Figure 5). There were seven scenes in total, including the Construction scene.

REFERENCES

- [1] Annette J. Dobson and Adrian G. Barnett. 2018. *An Introduction to Generalized Linear Models*. Chapman and Hall/CRC. <https://doi.org/10.1201/9781315182780>

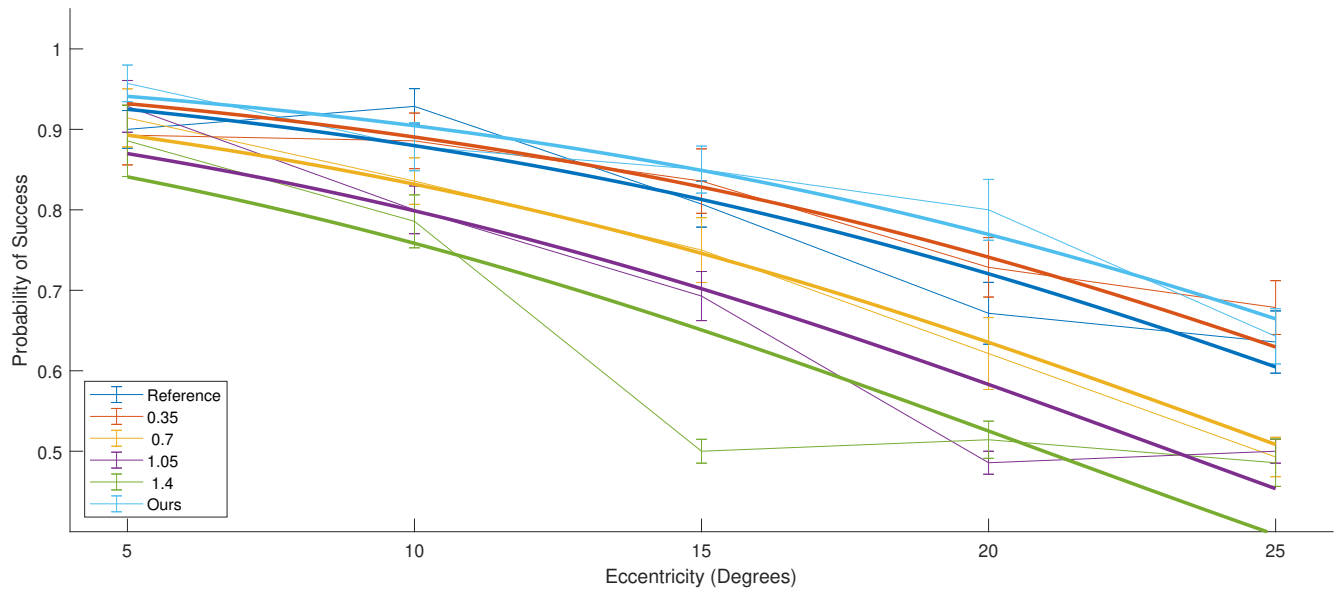


Fig. 1. Performance Study Results. Observed proportion of successes with Standard Error, and the fit lines of the model (Eqn. 1)



Fig. 2. Example stimuli from the Preference Study for the Construction scene

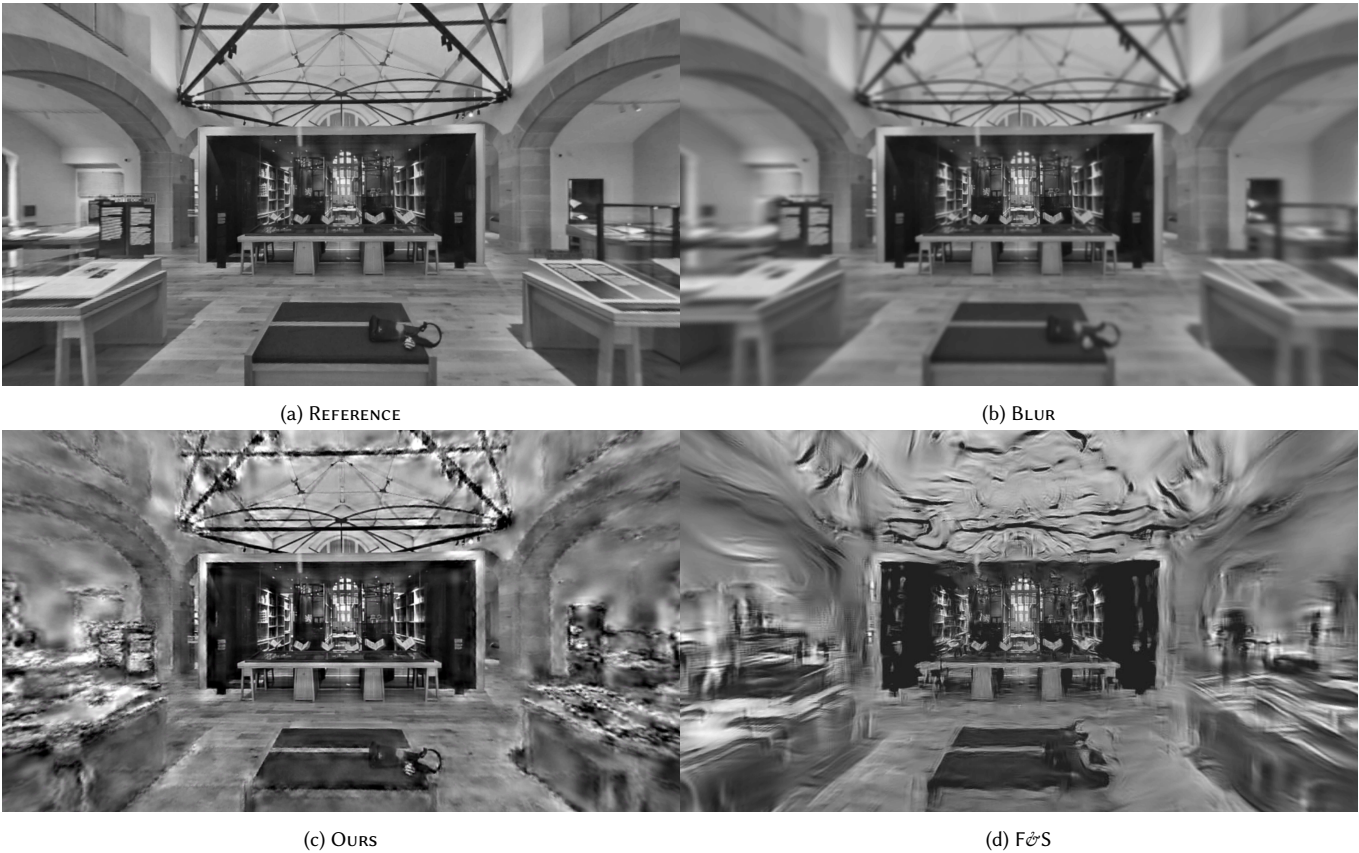


Fig. 3. Example stimuli from the Preference Study for the Gallery scene

Condition	Trials	Successes	N Choices		p-Value Success	p-Value Bias
			Consistent	Inconsistent		
Reference	420	351	351	69	<0.0001	<0.0011
F&S	840	405	289	551	0.317022636	<0.0001
Ours	840	427	651	189	0.653787342	<0.0001
Blur	840	419	551	289	0.972478559	<0.0001

Table 3. Results of the Detection Study, indicating the total number of Consistent/Inconsistent choices within a condition.

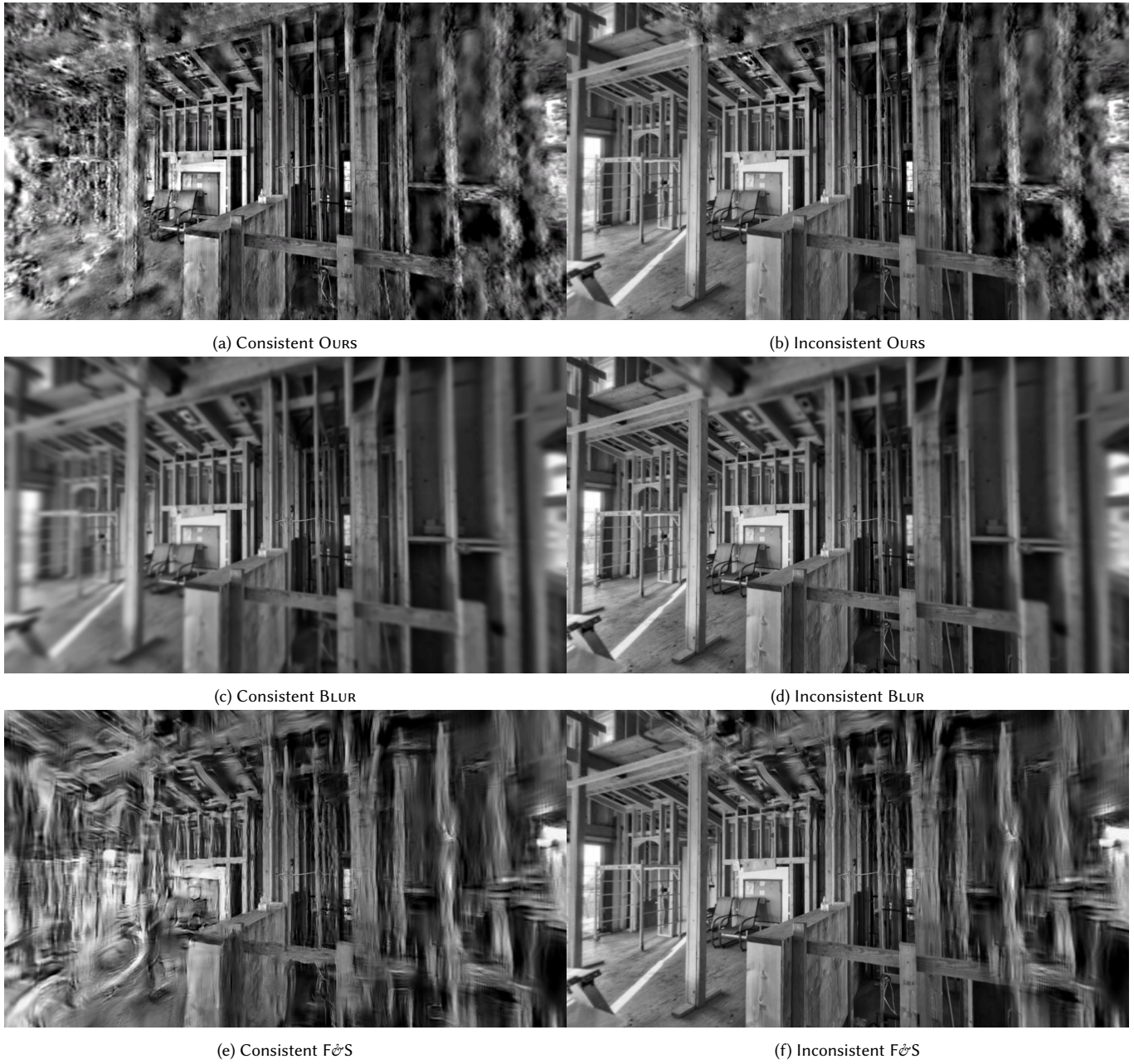


Fig. 4. Example stimuli from the Detection Study for the Construction scene



Fig. 5. Detection Study Reference for the Construction scene

A APPENDIX A - PARTICIPANT INFORMATION SHEETS

Participant Information Sheet

UCL Research Ethics Committee Approval ID Number: 4547-013

Title of Study: Foveated Acuity in VR

Department: Computer Science

Name and Contact Details of the Researcher:

- **Sebastian Friston**
- **sebastian.friston@ucl.ac.uk**

1. Invitation Paragraph

You are being invited to take part in a research project. During this study you will use your own HMD to view symbols in your periphery, and attempt to categorise them.

2. What is the project's purpose?

The purpose is to determine how different types of distortion in foveated rendering affects visual acuity.

3. Why have I been chosen?

You have been chosen because you have your own device and are capable of participating.

4. Do I have to take part?

Participation is completely voluntary and you may withdraw at any time.

5. What will happen to me if I take part?

You will be asked to download a Unity application and run this in your preferred HMD. A link is at the end of the document.

Putting on the HMD, you will see a White dot and a short set of instructions reminding you of the task. When you are ready, press any Answer button to begin the experiment.

During the study one of two symbols - C or O - will appear at a random location in your field of vision. The symbol will be visible for a fraction of a second. Once the symbol disappears, the dot will turn Green, indicating that you should respond. You should indicate which symbol you saw using one of the Answer buttons.

If you missed the symbol or were unable to make it out, press an Answer button at random to continue.

After you answer, another symbol will flash. The process repeats until the end of the experiment.

It is important you look directly at the small dot for the duration of the study. Do not look away from the dot until the experiment is complete.

Response time is not important. If you need to take a break, wait for the dot to turn Green, then remember your response and take as long as you like to enter it. You can remove the headset if you wish during this time.

The entire experiment should take no more than 20 minutes.

Once the experiment is complete, the application will close, and you may uninstall it.

6. Will I be recorded and how will the recorded media be used?

Only your answers are recorded. No other information is collected and all your data is completely anonymous.

7. What are the possible disadvantages and risks of taking part?

Some people get simulator sickness in VR. There is no movement in this experiment so the risk is minimal. Still if you have any adverse symptoms or feel discomfort, please exit the application and report them to the experimenter.

This study contains intermittent flashing and is not suitable for anyone suffering from Epilepsy.

8. What are the possible benefits of taking part?

There are no immediate benefits to taking part. It is hoped the results from this study will help inform foveated rendering for VR.

9. What if something goes wrong?

If you have any issues, in the first case please inform the researcher, Sebastian Friston (sebastian.friston@ucl.ac.uk).

If your issue is not resolved, in the second case contact Head of Group Anthony Steed (a.steed@cs.ucl.ac.uk)

In the third case, contact the Chair of the UCL Ethics Committee (ethics@ucl.ac.uk).

10. Will my taking part in this project be kept confidential?

All of the data collected is completely anonymous and cannot be de-anonymised.

11. Limits to confidentiality

The researchers must comply with any investigation from UCL or statutory bodies. However, all data is anonymous and cannot be de-anonymised.

12. Use of Deception

There is no deception used in this study, though minimal detail has been provided in the instructions to avoid introducing bias.

13. What will happen to the results of the research project?

The results of this study will be published in a journal.

14. Data Protection Privacy Notice

The data controller for this project will be University College London (UCL). The UCL Data Protection Office provides oversight of UCL activities involving the processing of personal data, and can be contacted at data-protection@ucl.ac.uk. UCL's Data Protection Officer is Lee Shailer and he can also be contacted at data-protection@ucl.ac.uk.

Your personal data will be processed for the purposes outlined in this notice. The legal basis that would be used to process your personal data will be the provision of your consent. You can provide your consent for the use of your personal data in this project by completing the consent form that has been provided to you.

If you are concerned about how your personal data is being processed, please contact UCL in the first instance at data-protection@ucl.ac.uk. If you remain unsatisfied, you may wish to contact the Information Commissioner's Office (ICO). Contact details, and details of data subject rights, are available on the ICO website at:

<https://ico.org.uk/for-organisations/data-protection-reform/overview-of-the-gdpr/individuals-rights/>

15. Who is organising and funding the research?

This project is funded by the EPSRC.

16. Contact for further information

Sebastian Friston, sebastian.friston@ucl.ac.uk

17. Links to Application

If you agree to take part, please sign the digital consent form then download the APK.

- Consent Form
 - <https://forms.gle/WRUvDcb24zxdkE5t5>
- APK for Quest
 - <https://www.dropbox.com/s/njuplwq6s57cm3w/PipelinesAcuity1.apk?dl=0>

Instructions can be found for installing the APK here, if required:

<https://uploadvr.com/sideloadng-quest-how-to/>

If you would prefer to run on a Desktop, please contact the researcher for a build.

Thank you for reading this information sheet and for considering to take part in this research study

Participant Information Sheet

UCL Research Ethics Committee Approval ID Number: 4547-013

Title of Study: Foveated Preferences in VR

Department: Computer Science

Name and Contact Details of the Researcher:

- **Sebastian Friston**
- **sebastian.friston@ucl.ac.uk**

1. Invitation Paragraph

You are being invited to take part in a research project. During this study you will use your own HMD to view pairs of images, and make a choice about which you prefer.

2. What is the project's purpose?

The purpose is to determine how different types of distortion in foveated rendering affects image preference.

3. Why have I been chosen?

You have been chosen because you have your own device and are capable of participating.

4. Do I have to take part?

Participation is completely voluntary and you may withdraw at any time.

5. What will happen to me if I take part?

You will be asked to download a Unity application and run this in your preferred HMD. A link is at the end of the document.

Putting on the HMD, you will see a White dot and a short set of instructions reminding you of the task. When you are ready, press any Answer button to begin the experiment.

During the study you will be shown two images, one after the other, for roughly half a second each, with a short pause in between in which the screen will turn gray. After both images are shown, you should indicate which you preferred by pressing the appropriate button (Left for

the First image, and Right for the Second image). When it is time to answer, the dot will turn Green and a prompt will show.

After you answer, another set of images will be displayed. This process will repeat until you have seen all image pairs.

If you cannot see a difference or do not have a preference, answer randomly.

It is important you look directly at the small dot for the duration of the study. Do not look away from the dot until the experiment is complete.

Response time is not important. If you need to take a break, wait for the dot to turn Green, then remember your response and take as long as you like to enter it. You can remove the headset if you wish during this time.

The entire experiment should take no more than 15 minutes.

Once the experiment is complete, you may close and uninstall the application.

6. Will I be recorded and how will the recorded media be used?

Only your answers are recorded. No other information is collected and all your data is completely anonymous.

7. What are the possible disadvantages and risks of taking part?

Some people get simulator sickness in VR. There is no movement in this experiment so the risk is minimal. Still if you have any adverse symptoms or feel discomfort, please exit the application and report them to the experimenter.

This study contains intermittent flashing and is not suitable for anyone suffering from Epilepsy.

8. What are the possible benefits of taking part?

There are no immediate benefits to taking part. It is hoped the results from this study will help inform foveated rendering for VR.

9. What if something goes wrong?

If you have any issues, in the first case please inform the researcher, Sebastian Friston (sebastian.friston@ucl.ac.uk).

If your issue is not resolved, in the second case contact Head of Group Anthony Steed (a.steed@cs.ucl.ac.uk)

In the third case, contact the Chair of the UCL Ethics Committee (ethics@ucl.ac.uk).

10. Will my taking part in this project be kept confidential?

All of the data collected is completely anonymous and cannot be de-anonymised.

11. Limits to confidentiality

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12. Use of Deception

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13. What will happen to the results of the research project?

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- Consent Form
 - <https://forms.gle/4jMwVK7zUjACQBx5A>
- APK for Quest
 - <https://www.dropbox.com/s/12525555bgyaoh4/PipelinesPreference1.apk?dl=0>

Instructions can be found for installing the APK here, if required:

<https://uploadvr.com/sideloadng-quest-how-to/>

If you would prefer to run on a Desktop, please contact the researcher for a build.

Thank you for reading this information sheet and for considering to take part in this research study.

Participant Information Sheet

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Department: Computer Science

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You are being invited to take part in a research project. During this study you will use your own HMD to view images and attempt to determine whether or not they are consistent.

2. What is the project's purpose?

The purpose is to determine how different types of distortion in foveated rendering affects visual perception.

3. Why have I been chosen?

You have been chosen because you have your own device and are capable of participating.

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Putting on the HMD, you will see a White dot and a short set of instructions reminding you of the task. When you are ready, press any Answer button to begin the experiment.

During the study you will be shown an image for a short period. The image will have an effect applied to it. You must determine whether the effect has been applied *consistently* or *inconsistently* across the image. Examples of each are shown below.

Inconsistent Images	Consistent Images
	
	
	
	

There may or may not be an equal number of consistent/inconsistent images in your trial.

Once the image disappears, the dot will turn Green, indicating that you should respond. You should indicate whether the image was consistent or inconsistent using the Answer buttons.

If you missed an image, press an Answer button at random.

The process repeats until the end of the experiment.

It is important you look directly at the small dot for the duration of the study. Do not look away from the dot until the experiment is complete.

Response time is not important. If you need to take a break, wait for the dot to turn Green, then remember your response and take as long as you like to enter it. You can remove the headset if you wish during this time.

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