# TOBII BENCHMARK TESTING VALIDATES THE BENEFITS OF DYNAMIC FOVEATED RENDERING

## INTRODUCTION

Led by enterprise use cases, the VR market is resurging with a new generation of devices equipped with innovative features enabled by eye tracking and foveated rendering (FR). These technologies first appeared in commercial headsets in mid-2019, and while they are relatively new, they promise to deliver significant improvements in performance and the generation of accurate, actionable insights. Heavy M&A activity in the eye-tracking space has consolidated the market to just a few players. Tobii is one of the remaining independent eye-tracking companies that offer OEMs the opportunity to integrate eye tracking into their products and reap the benefits that come with this technology.

HTC's Vive Pro Eye headset, for example, now delivers dynamic foveated rendering (DFR) through the combination of Tobii Spotlight Technology and NVIDIA's Variable Rate Shading (VRS) – two technologies that have long been in the works. Using information about what the user is looking at, DFR limits high-resolution rendering to the user's gaze point. Fixed foveated rendering (FFR) reduces the need for high-resolution to areas where the user is less likely to notice, with only a moderate impact on performance but does not dynamically change as the eye moves. In addition to the HTC PC platform, Tobii has partnered with Qualcomm to integrate its eye-tracking solution into Qualcomm's standalone extended reality (XR) platform, including the recent Snapdragon XR2 reference design. For standalone headsets, Pico's Neo 2 Eye is the first commercial VR headset integrated with Tobii's eye-tracking solution. As more XR headsets come out with eye tracking, it is starting to become an expected feature, especially for enterprise users.

## BENCHMARK PURPOSE

The main benefit of foveated rendering is reduced GPU load. To achieve this, high-resolution rendering is limited to just a small area of the screen with the remainder rendered at a lower, less-costly resolution. With DFR, this area of high resolution follows where the user's gaze is focused, maximizing the quality of the user experience. To enable FR with HTC's new Vive Pro Eye headset, Tobii partnered with NVIDIA to utilize the VRS capability, which is part of NVIDIA VRWorks.

With commercially available VR headsets equipped with FR and FR-enabled graphics cards, we can now quantify the benefits of foveated rendering. Tobii conducted benchmark testing to illustrate the benefit of combining Tobii Spotlight Technology with NVIDIA's VRS by measuring the rendering workload improvements provided by FR.

## BENCHMARK COMPONENTS

### *HARDWARE*

Tests measuring the DFR capability of the HTC Vive Pro Eye VR headset utilized an Alienware Aurora desktop gaming PC configured as shown below:

## TABLE 1: ALIENWARE AURORA PC HARDWARE SPECIFICATIONS

| | |
|---|---|
| CPU | Intel Core i7 Processor 8700K |
| GPU | ASUS GeForce RTX 2070 & 2080 Ti |
| Memory | 16GB Dual Channel DDR4 at 2666MHz |
| Storage | 512GB M.2 PCIe Solid State Drive |
| Graphics Card Model | NVIDIA RTX 2070 and 2080 Ti graphics cards powered by NVIDIA's RTX technology and Turing architecture, which enable VRS |
| I/O | DisplayPort |

In addition to PC testing, Tobii ran similar tests on the Pico Neo 2 Eye using a Tobii-developed FR demo.

## TABLE 2: PICO NEO 2 EYE SYSTEM SPECIFICATIONS

| | |
|---|---|
| CPU | Snapdragon 845 |
| GPU | Adreno 630 |
| Memory | 4GB |
| Storage | 128GB Storage |
| Graphics Card Model | Adreno 630 |
| I/O | N/A |

### SOFTWARE

The software used in testing included Microsoft Windows 10 combined with NVIDIA's graphics drivers for the base-level installation and Unreal Engine (Unreal Engine v4.2) as the host engine for the benchmark/demo. The Unreal Engine demo is an open-source demo originally developed by Epic Games called Showdown; it was originally used as a graphics demo for VR when Unreal Engine was updated with new features specifically made for early VR platforms. To capture performance data, Unreal profiler was used to gather precise information about the state of each frame as it was generated by the GPU and sent to the headset through the game engine. Tobii created its own Unity test scene for VR that allowed for reproducible results and enabled validation of performance consistency across game engines. SteamVR was also a key part of the test configuration as it allows the HTC Vive Pro Eye headset to seamlessly communicate with the operating system and graphics card with optimal performance.

## TABLE 3: ALIENWARE AURORA PC SOFTWARE SPECIFICATIONS

| | |
|---|---|
| Operating System | Windows 10 v 1903 |
| Graphics Drivers | NVIDIA (416.34) |
| Host Engine | Unreal Engine (4.20)<br>Unity Engine (2019.2.9f1) |
| Demo | Showdown (open source from Epic Games)<br>Adam Interior Environment (Unity) |
| GPU Profiler | Unreal Profiler<br>Unity Profiler |
| HTC Vive Pro Eye headset Driver | SteamVR (1.6.10) |

### CONFIGURATION/SET UP

The configuration used the HTC Vive Pro Eye — plugged in via USB and DisplayPort to the NVIDIA RTX 2070 GPU or RTX 2080 Ti — with the demonstration running and the eye tracking enabled through a runtime that connects to the sensors in the headset. A monitor was connected to the RTX 2070 or RTX 2080 Ti inside of the Alienware Aurora; the monitor scanned the demo/benchmark as it ran to replicate a common user's setup

and show the demo running in real-time. However, having a monitor connected did not meaningfully impact total performance, as it did not do any 3D rendering.

The test required three different runs, each of which resulted in different shading densities: a baseline where VRS is disabled (full rendering), VRS static foveation with fixed foveated rendering (FFR), and VRS dynamic foveated rendering (DFR) enabled by Tobii's Spotlight Technology. VRS disabled resulted in 100% shading density, while VRS static foveation resulted in 41.25% shading density and Tobii's dynamic foveated rendering resulted in a shading density of 16%.

To simulate heavier content, some scene modifications were made to the Showdown demo, including the addition of extra lights and increased resolution. Physically based rendering was enabled, and texture sizes ranged from 1024 up to 4096. Super sampling in SteamVR was also enabled to allow for a more high-resolution test to stress the graphics more effectively. This configuration was used for both the RTX 2070 and RTX 2080 Ti.

For the standalone platform, the Pico Neo 2 Eye was tested using Adreno Foveation, which leverages Tobii Spotlight Technology to track the user's eye movements, rendering just the area where the user is looking in full quality. Adreno Foveation is a feature of Qualcomm's Snapdragon SoC GPU and is similar to NVIDIA's GPU with VRS. These features are enabled on the hardware, but developers still need to modify the application to take advantage of them.

## BENCHMARK PROCESS

After the HTC Vive Pro Eye is plugged into the system (assuming it has already been installed correctly), the Unreal Engine profiler must be turned on to capture frame rates and times. The headset needs to be placed on a static surface and not moved at all during the benchmark. This removes potential variables, creating a stable and repeatable benchmark. Tobii ran this benchmark with numerous different head positions to remove any bias a position might have on the results due to the variance of detail in different places. Additionally, because no user is wearing the headset directing the area of foveation with their gaze, eye tracking defaults to a centered position, performing foveated rendering in the middle of the display area. However, Tobii also ran tests with 10 different users wearing the headset to validate these results. While benchmarking with people produces a less consistent test environment, it also provides important real-world validation of the results.

The Unreal Engine Showdown demo runs on a set path, ensuring that the same effects and animations run at the exact same moment every time the test runs, reducing the need to create a scripted path for any potential game or application to follow. The Tobii benchmark test captured Unreal Engine Profiler data — frame times and rates, as well as GPU shading load — in CSV format. The baseline benchmark ran with NVIDIA VRS off, establishing the level of performance without foveated rendering or variable rate shading. After the baseline was set, the benchmark was run with NVIDIA VRS on. This test allowed performance results for static foveation to be obtained, showing the improvements to performance without any eye tracking but with foveated rendering.

Once those two levels of performance were established, the third and final performance benchmark was conducted with Tobii Spotlight Technology enabled and VRS on, allowing Tobii to obtain performance information for dynamic foveated rendering. This third result is compared to the baseline, where performance is worst-case-scenario. GPU render loads can be obtained from the Unreal Engine Profiler while the benchmark is running, and the numbers can be easily compared to one another using the render load numbers calculated by the profiler.

The Unity demo was built using a series of Unity store samples, including the Adam demo that Unity created of a robot inside of a spaceship depicting a very high-quality 3D model of a robot. The Unity demo also used NVIDIA VRS with the same methodology as the Unreal Engine demo. In addition, Tobii ran all three versions of the benchmarks at higher resolutions using the SteamVR by super sampling to simulate higher-resolution headsets (ranging from 1x to 3x native resolution).

## BENCHMARK RESULTS

To see the improvement in shading load, the load of each scenario is compared to the base load. Based on Tobii's benchmark testing and results, there was a major reduction in shading load, as much as 57%, when comparing dynamic foveated rendering against disabled VRS. The significant reduction was accomplished at an average shading rate of 16% (compared with the baseline of 100% without VRS enabled). Moor Insights & Strategy witnessed these results in person during the benchmarking process, and we also reviewed the data that supports this outcome.

## RTX 2070 Results

### Unreal Engine

| | FULL SHADING LOAD | DFR SHADING LOAD | REDUCTION |
|---|---|---|---|
| 1x super sampling | 23.49% | 10.06% | 57.19% |
| 3x super sampling | 59.68% | 23.81% | 60.10% |

| RESOLUTION | FULL RENDERING | FFR PIXELS LOAD | DFR PIXELS LOAD |
|---|---|---|---|
| 1K | 2,097,152 | 859,832 | 335,544 |
| 2K | 8,388,608 | 3,439,329 | 1,342,177 |
| 3K | 18,874,368 | 7,738,491 | 3,019,899 |
| 4K | 33,554,432 | 13,757,317 | 5,368,709 |
| 5K | 52,428,800 | 21,495,808 | 8,388,608 |
| 6K | 75,497,472 | 30,953,964 | 12,079,596 |
| 7K | 102,760,448 | 42,131,784 | 16,441,672 |
| 8K | 134,217,728 | 55,029,268 | 21,474,836 |

### Unity

| | FULL SHADING LOAD | DFR SHADING LOAD | MAX REDUCTION |
|---|---|---|---|
| 1x super sampling | 13.6% | 5.46% | 59.85% |

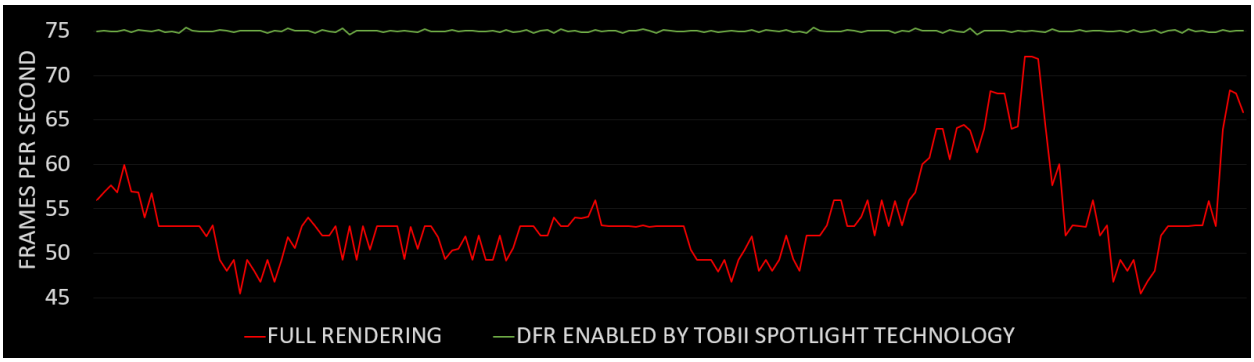
## RTX 2080 Ti Results

| | ENGINE | MAX REDUCTION |
|---|---|---|
| 1x super sampling | Unreal | 59.37% |
| 1x super sampling | Unity | 59.85% |

### Pico Neo 2 Eye

| | ENGINE | MAX REDUCTION |
|---|---|---|
| 1x super sampling | Unity | 72.21% |

## FIGURE 1: DYNAMIC FOVEATED RENDERING VS FULL RENDERING




*Source: Tobii*

These results imply that manufacturers can realize significant GPU load reductions by installing Tobii Spotlight Technology on their headsets and enabling applications to run with NVIDIA's VRS technology or Adreno Foveation. Such load reductions can lead to exciting possibilities such as running headsets on less powerful GPU systems, enabling higher resolutions on headsets without the need to install more powerful GPUs, and unlocking features such as ray tracing that render realistic high-quality graphics.

For standalone VR headsets, such as the Pico Neo 2 Eye, foveated rendering enables devices to deliver a much more consistent experience at a reliable frame rate, with lower dependency on the complexity of the scene. Because standalone VR headsets are power and performance sensitive, a technology that evens out the frame rate — increasing it and ensuring consistency — is a welcome improvement. The user-experience benefits are much more impactful for mobile platforms utilizing foveated rendering using Tobii Spotlight Technology. Having the ability to tweak a device's performance and battery life based on foveated rendering can allow OEMs to build more affordable and more comfortable VR headsets.

For example, foveated rendering can improve the quality of VR games and enterprise applications without affecting performance. It can also help more affordable headsets run titles at a quality level similar to higher performance headsets that don't have foveated rendering. This can make some OEMs more competitive in a marketplace where resolution is a popular feature but is often considered as a possible performance inhibitor without the presence of eye tracking.

## EVALUATION

The Tobii Spotlight Technology benchmark for PC and Standalone VR, in our opinion, is a good benchmark for the current state of foveated rendering and adequately quantifies the GPU render-load savings that dynamic foveated rendering offers. We believe that this benchmark used standard, industry-approved software, hardware, and methods to accurately compare VR with and without DFR. The current availability of applicable hardware and software is limited, which consequently limits complete setup testing to just a few configurations, and we believe that Tobii did a good job of testing those possibilities.

Tobii's testing of both Unity and Unreal engine was key to helping developers understand that the benefits are not engine-specific and that virtually any VR application could benefit greatly from FR. It also reflects well upon Tobii that the company is a leader in enabling and quantifying DFR, giving the industry a good starting point to improve upon. Tobii's leadership role in the VR/AR industry is important because we need quantifiable ways of measuring VR performance with foveated rendering.

Tobii's testing of no VRS, static foveation, and DFR was a good choice as it presented best-case and worst-case scenarios as well as the middle ground. We believe that it was a good decision for Tobii to use the HTC Vive Pro Eye and Pico Neo 2 Eye devices due to the resolution features and built-in Tobii Spotlight Technology. It was also a good decision to run the tests without a user wearing the headset to minimize variance, given that human head movements cannot be controlled. We believe that Tobii's process was thorough and produced results that can be replicated easily, which is important when making a critical assessment of the benefits of a feature such as Tobii Spotlight Technology.

Tobii also conducted real-life user testing to determine whether the results could be reproduced when a user was wearing the headset. For the most part, results were replicated. The main issue with user testing is that people look at different things at different times during a benchmark, which potentially affects what gets rendered and consequently what frame rate can be achieved. That said, there is nothing more real-world in terms of testing than having an actual user wearing the headset during the benchmark.

### *VR INDUSTRY OUTCOME*

The Tobii Spotlight Technology benchmarks should serve as a standard for the VR industry as eye tracking increasingly becomes an expected capability of XR headsets

and user expectations grow. The benchmarks allow VR headset OEMs to understand the quantitative value of integrating features such as DFR with Tobii Spotlight Technology. Establishing Tobii as a thought leader in the AR/VR industry, the benchmarks also set a standard from which the industry can improve and deliver better experiences and better devices.

PC and Standalone VR OEMs can benefit from the results of this benchmark study because headsets with DFR are shown to operate on a broader array of performance levels and not just the top tier, which is still an ongoing issue. The OEMs can also make design, performance, and cost decisions about what components to order for their next VR headsets if they plan to use Tobii Spotlight Technology. Additionally, the improved frame rate and additional GPU render load enables developers to add enhanced graphical features or improve image quality with higher resolution textures.

These are just some of the benefits that can be realized today with the reduction in the GPU graphical rendering load delivered by dynamic foveated rendering. One could also reasonably expect eye tracking to deliver measurable benefits in user experience, user interface, and other analytical data which enterprises thrive on. Results for consumers and enterprise users could include the ability to afford high-quality headsets, or that high-end headsets could continue to drive higher pixel densities without a significant impact to system performance.

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