# Game-day football visualization experience on dissimilar virtual reality platforms

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## ABSTRACT

College football recruiting is a competitive process. Athletic administrations attempt to gain an edge by bringing recruits to a home game, highlighting the atmosphere unique to campus. This is however not always possible since most recruiting efforts happen off-season. So, they relate the football game experience through video recordings and visits to football facilities. While these substitutes provide a general idea of a game, they cannot capture the feeling of playing while cheered on by a crowd of 55,000 people. To address this challenge and improve the recruitment process, the Iowa State University (ISU) athletic department and the Virtual Reality Applications Center (VRAC) teamed up to build an alternative to the game-day experience using the world's highest resolution six-sided virtual reality (VR) environment - the C6, and a portable low-cost head-mounted display (HMD) system. This paper presents techniques used in the development of the immersive and portable VR environments followed by validation of the work through quantifying immersion and presence through a formal user study. Results from the user study indicate that both the HMD and C6 are an improvement over the standard practice of showing videos to convey the atmosphere of an ISU Cyclone football game. In addition, both the C6 and HMD were scored similar in immersion and presence categories. This indicates that the low-cost portable HMD version of the application produces minimal trade off in experience for a fraction of the cost.

**Keywords:** College Football, Immersive Game Day Experience, Virtual Reality Football, Football User Study, Head-Mounted Display, HMD vs Immersive VR, Oculus Football, Immersive Football Experience

## 1. INTRODUCTION

The game of college football is an increasingly competitive, publicly visible, and debated sport. It can captivate the nation and bring priceless publicity to schools. This is especially true among the ranks of division one teams. Often the success or failure of a team is determined before they even step on to the field. In fact the team's success is determined years ahead of time through the laborious time intensive process of recruiting. Recruits who commit to the team can lay the foundation for success or failure in the years to come. With the prevalence today of multimillion-dollar athletics budgets and the focus on winning seasons, recruiting is a high stakes game where even the slightest edge can pay significant dividends. As a result, schools are looking for any advantage they can gain. Often the recruiting teams seek to brand their school in an effort to make it seem unique[1,2,3]. An example of this branding is Boise State's signature blue turf[4] or Oregon State's flashy ever-changing uniforms[5].

One of the ways schools highlight unique aspects is to bring recruits to home football games. Each college stadium on game day takes on traditions and characteristics unique to that campus. Highlighting these unique traditions to recruits during the off-season can be challenging. This is mostly due to only a handful of home games a year. With only a limited number of opportunities in a year to visit, recruiting staff is hard pressed to coordinate numerous recruits' schedules around the limited games. These challenges can result in a recruit coming during the off-season or on a weekend when there is no home game. Meaning they get less than the full game day experience. When recruits visit during the time when a game is not scheduled, at least for Iowa State University (ISU), they are taken on a tour of facilities such as the empty stadium and shown videos of past games. While these substitutes provide a general idea of an environment, a recruit cannot fully imagine himself playing cheered on by a crowd of 55,000 people[6]. In addition to the challenges of coordinating schedules, some recruits may not be able to visit campus at all making it even harder for recruiting staff to convey what game day is like. Due to the on site visitation challenges presented above, the process is made more

effective if the recruiting staff is better able to convey the game day experience regardless of the time of year. While physical visits to an actual home game provide the best feel for a games atmosphere, the need for an alternative next best experience for on-campus or off-campus recruitment efforts during off-season was recognized[7].

These challenges described above present a unique opportunity to use Virtual Reality (VR) to improve upon the current off-season process by attempting to create a realistic game day experience. VR technology excels at replicating environments and creating a sense of presence[8,9]. As part of the initiative to improve the recruitment process, the ISU athletic department and the Virtual Reality Applications Center (VRAC) teamed up to build a VR simulation of the Iowa State Cyclone game-day experience using the world's highest resolution six-sided VR environment - the C6, and a portable low-cost immersive VR system. The portable system works to provide a similar experience to the C6, only in a recruit's home off-campus. While building an immersive game-day experience is a challenging task, quantifying its effectiveness over traditional recruiting methods is another. To quantify the effectiveness of the application on different platforms over the standard practice of showing videos to convey a game day atmosphere, the authors conducted a formal user study measuring presence and immersion. The results of the formal user study presented in this paper provide insight into the differences in immersion and user perception between the portable low-cost HMD system, the multi-million dollar C6, and the standard video demonstration of past game days.

## 2. BACKGROUND

### 2.1 Immersion and presence in virtual environments

Immersion is generally the objectively measured attributes of the technology that goes into creating an experience[18], such as the screen resolution, interaction mode, frame rate, head tracking, field of view, and sound quality[10]. Presence, however, is a subjective measure involving convincing the user that they are actually someplace else, a sense of "being there"[11,12]. Inducing a sense of presence in the user is important to convince them that they are in fact experiencing a realistic alternate reality. If users think that they are indeed in another environment they are more apt to fluidly interact with the simulation and believe what they are being shown, increasing the effectiveness of the simulation[13]. Understanding what factors contribute to immersion and presence is key to producing a quality application. In order to assess a virtual environment and compare different systems there needs to be a way to qualitatively measure these key variables. Witmer and Singer have done extensive research on measuring presence and immersion[11]. Their questionnaires have gone through multiple iterations and been used in countless studies[14]. Due to the accepted nature of the Witmer and Singer measures of immersion and presence the authors decided to utilize the method to measure the effectiveness of the game day application across multiple platforms.

Numerous studies have been conducted on virtual environments to evaluate their effectiveness at offering highly realistic alternatives to actual experiences. A large portion of this previous research centers on measuring or quantifying what produces or impacts users' immersion and presence within a system[15,16,17,18,19,20]. Loftin et al. shows through a military training study that VR has the potential to produce a convincing virtual experience that facilitates skill and knowledge transfer[9]. In this study, they demonstrated that interactive VR could quickly train novices in standard military procedures. Research in the medical field demonstrates that the presence created in VR environments can be used for treating a host of psychological ailments[21,22,23]. In addition, Kwon et al. concludes that VR environments with low degrees of graphical realism can reproduce anxiety levels in users for a job interview[24].

### 2.2 VR in sports

Bouchard et al. and Craig et al. have shown the feasibility of VR simulations to provide realistic training for sporting applications. VR is attractive due to its ability to accurately model what is taking place and provide flexibility over traditional practice modes[25,26]. Craig also discusses the benefits to the sports world when using VR[27]. The research illustrates how the current mode of video for reviewing sporting applications is inadequate and that VR provides flexibility to control the scene and the elements in that scene. Ultimately Craig points out that using VR is most advantageous due to the flexibility it provides. In addition, the research identifies that VR's high degree of realism can not only help accurately model sporting events, but can also capture nuanced situation specific moments[26]. This can help provide athletes with a more accurate understanding for a situation than standard video.

Miles et al. reviews a number of previous VR related works in the world of sporting simulations[28]. Their work concludes that VR environments can provide great flexibility in creating realistic simulations. In addition they find that, highly detailed graphics, accurate physics and real-time interaction are required for believable sporting simulations.

Prior research was also done in studying the benefits of high-end expensive CAVE[TM] systems and low-end portable HMDs. Bowman et al. highlighted in their research how the choice of a head-mounted display (HMD) or CAVE can impact the users perception of an application[8]. They argue that the factors influencing the users perception between HMDs and CAVEs are not fully understood. As a result they advocate user studies as a way of testing user perception of a system on different platforms. While VR environments have their shortcomings the potential they provide to enhance the training and sporting experience is promising. Previous research has been done on how VR can help improve skills and provide athletes with a feel for a particular scenario[29,30,31,32,33,34].

High-stakes situations are common in sports. The last second goal line stand or the must make catch can induce significant stress in athletes. Research by Wellner et al. indicates that VR environments can even reproduce the stress associated with a particular sporting situation[35]. They created a high fidelity simulation of a rowing competition. The close modeling of an actual rowing scenario caused competitors to exhibit real world strategies to deal with changes in the race dynamic. Similarly, Fajen et al. found that VR simulations could help recreate affordances found in sports because of its ability to create highly accurate and realistic scenarios, transporting the user and making them believe that they are in fact actually experiencing the simulation[36].

## 2.3 Research challenges identified

Traditional VR systems like CAVEs typically require stereo projectors, screens, stereo emitters for synchronization with active stereo glasses, spatial surround audio, and computer cluster environments to render content. They require a large capital investment and consume time, money and also sizeable real estate to run, maintain and operate the system[7,37]. These challenges identify a need for low-cost alternatives such as HMDs. HMDs come in many variations differing in their resolution, field of view, tracking capabilities, etc., and different vendors offer distinct advantages over the others[38]. For their price, form and function, HMDs are quite portable and provide capabilities similar to full immersive VR CAVE systems[12,39] and possibly offer a competitive advantage for addressing certain problems.

A need for a virtual game day experience to improve off-season recruitment process was identified in the introduction section. The Virtual Reality Applications Center (VRAC) at ISU was tasked with developing a high-end and a low-cost portable virtual game day experience to address this need. Typical video games come with features such as dynamic frustum culling, and non-essential elements in the environment can be rendered with a lower LOD. Unfortunately, immersive VR environments do not have such privileges and applications should scale reasonably and perform consistently across immersive displays as well as portable HMDs, while maintaining interactive frame rates. Given the application's focus on re-living a game-day experience, its implementation presents a formidable challenge especially with requiring detailed geometry/animation elements such as the stadium, the players, marching bands, audience, cheerleaders, etc. This is identified as a first challenge that is addressed in this paper.

On the other hand, the sheer dissimilarity between immersive CAVEs and HMD hardware raised the issue of how much immersion and presence can they can induce on a potential recruit. Additionally, it remains to be seen whether this new recruiting technique is any more effective than the traditional video demonstrations. Although there is previous research comparing portable and full immersive VR systems, virtual game day experience is intended for a targeted purpose and only a formal study can tell the measure of effectiveness.

In this paper, the design and development of a virtual college football game day experience for full immersive CAVE and portable HMD systems is described. Further, a formal user study comparing the user experience on high-end and low-end VR systems is described. Further, these two modes are compared and their effectiveness is measured against traditional video demonstration strategies at ISU. Conclusions are then drawn on whether a full immersive CAVE, low-cost portable HMD, or the video mode offers the best means of recruiting.

# 3. METHODOLOGY

This section is broadly divided into two main topics: a) VR application development, and b) User studies.

## 3.1 VR application development

### 3.1.1 CAVE system specifications at ISU

The Virtual Reality Applications Center (VRAC) at the Iowa State University hosts the world's highest resolution stereoscopic visualization and interaction experience, called the C6. It is a six-sided virtual reality room consisting of six

10' x 10' display screens arranged in a cube. These screens are rear-projected by 24 Sony SRX-S105 4K projectors, four per wall. Passive video signals from the projectors are converted into active stereo with LCD beacons positioned in front of the projectors. Therefore, two of the four projectors on a wall emit signals for the left-eye and the other two for the right-eye. Additionally, the LCD panels are equipped with passive filters thereby allowing active and passive stereo experience within the C6. **Figure 1** shows the arrangement of the C6 display screens and the projectors. A 48-node Dell six-core Intel Xeon cluster, each housing two Nvidia Quadro 6000 video cards, one per-eye powers the C6. Therefore, 96 channels of video signal are uniformly split between left- and right-eyes. A master node with similar specifications as the cluster nodes is used as an interactive terminal to launch applications in the cluster. Further, the C6 uses ultrasonic Intersense IS-900 tracking system and also supports 8.1-channel surround audio.
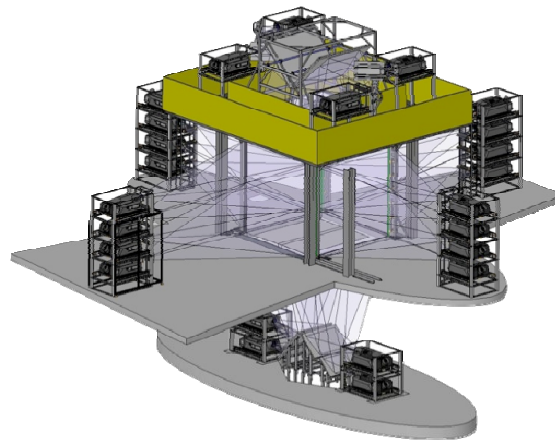


**Figure 1.** Layout of the C6 at VRAC

### 3.1.2 Framerate challenges in immersive VR

Although the Nvidia Quadro 6000 GPUs[40] used in the C6 cluster are scientific grade and are capable of rendering more than a billion triangles per second, a seamless visualization experience from content delivered to the screen is affected by a number of factors: a) Framelocking, to synchronize the timestamps of frames, b) Genlocking, to enable synchronization of frame timings, c) Software TCP swap lock, to make sure the master node delivers identical content to all cluster nodes. Without enabling these three factors, the user typically experience visible 'application tearing', which is characterized by images being generated by one of the cluster nodes proceeding faster or slower than the other nodes. Enabling them will keep images from all nodes in sync. However, this synchronization imposes overhead on the content, resulting in decreased framerates.

On the other hand, the software API used for generating and displaying content will also add an overhead, depending on how it is implemented. Interaction devices such as a game controller or keyboard are typically connected to a master node. Therefore any transformation triggered from an interaction device or an animation occurring within the scene should be broadcasted to the entire cluster via network communication from the master node every frame, adding additional overhead on the framerate. This overhead increases, as the number of nodes in the cluster is higher. Therefore, applications that execute at interactive framerates on a standalone computer workstation will run at a fraction of that framerate when executed in a cluster VR environment although the hardware specifications of each node and the standalone workstation might be identical.

### 3.1.3 Low-cost portable HMD system

VRAC owns a few second-generation DK2 Oculus Rifts[41], which were chosen as candidates for low-cost portable VR devices. These display devices are capable of 960 x 1080 pixel resolution per eye, with a $100^0$ field of view. They also come with internal and positional tracking hardware, so the visual content can re-adjust itself based on the direction and orientation the user is looking at. This device is a favorable trade-off in price, resolution, field of view, usability, and programmability compared to other competitors such as Sony HMZ-T1[42], and nVisor ST60[43], etc, and hence used as the portable HMD for this research.

### 3.1.4 Choice of development environment

Development of the VR application hinged on the following narrowed down requirements: a) Application should be easily clusterized, b) Avatars such as football players, marching band 3D models should be easily programmable, c) Able to replicate the environment on both immersive CAVEs and the Oculus Rift HMDs alike. A number of open-source and commercial graphics APIs such as OpenGL[44], OpenSceneGraph[45], and WorldViz Vizard[46], were investigated as possible candidates. None of these APIs were a one-stop solution for all the requirements listed above. However, the game engine Unity 3D[47] showed a significant advantage over other APIs because of its simplicity in scripting a VR environment, including avatar animations and a suite of features that simplifies programmer burden, as well as its support for Oculus Rift HMD.

getReal3D, a third-party Unity 3D plug-in was developed by Mechdyne[48], to pipe applications developed using Unity 3D into a visualization computer cluster. getReal3D spawns instances of the Unity 3D application on each node of the cluster and also manages viewport clipping for continuous display across cluster nodes. In addition, game object transformations and updates triggered on the master node are broadcasted to the cluster in synchronization via network communication. getReal3D daemons on each cluster node continuously listens for these updates and applies them as sequence of commands to Unity 3D's game objects. Although Unity 3D can generate game executables for different platforms and operating systems, getReal3D is a windows based application and required that the visualization cluster was booted into Windows operating system for cluster management.

Depending upon the number of game objects that contain transformation updates, heavy network traffic is possible affecting the overall framerate of the application in the immersive C6. This is an unavoidable situation, although the degree of network traffic could be lesser if a natively supported clusterization component within Unity 3D were available. At the time when the authors began working on the project, Unity 3D did not have clusterization capabilities. In favor of time and costs, the third-party getReal3D was chosen as the clusterization component within Unity 3D for the C6.

For the Oculus Rift, a Unity 3D plug-in developed by Oculus[49] was used. Since there was no additional scripting overhead apart from setting an Oculus display mode in the Unity 3D authoring environment for the requirements of this project, a near develop once and deploy on multiple platforms (i.e., the C6, and the HMD) became feasible.

### 3.1.5 Elements of game day application

The athletics department at ISU stipulated a list of requirements in the VR application that best resonated the school's football culture and branding, so it invigorates a recruit's desire to become a part of the team. Some of the most prominent ones were:

1. Marching band and cheerleading performances
2. Cyclones storm warning video played on north and south scoreboards in the field
3. Opposing team's players taking the field while being booed by the stadium crowd
4. Cyclones entering the field though an inflatable tunnel and form a huddle
5. Stadium crowd singing sweet caroline song
6. An offensive and a defensive play

At the time of performing user studies and writing the article, offensive and defensive plays were not incorporated yet as the project is still on-going. However, the other requirements listed were implemented. Geometry for the Jack Trice football stadium was acquired from the stadium's design architects which was later reduced and converted into a file format compatible with Unity 3D. Geometry and game animation elements such as football players, marching band members, and cheerleaders were sourced from Unity 3D asset store[50], TurboSquid[51], and Mixamo[52]. Autodesk Maya[53] was used for custom animations and polygon count reduction. While Mixamo facilitated polygon reduction as well, it was most beneficial for this project with auto-rigging and applying animations (e.g., running, somersaults, dance routines) of avatars. Custom textures were created in Adobe Photoshop[54]. Figure 2 shows relevant avatars modeled and used in the application.
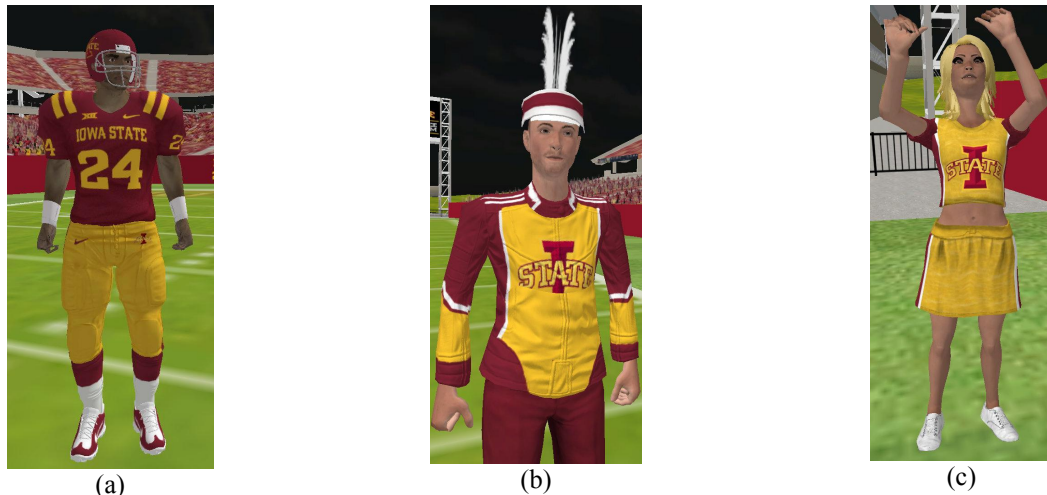
**Figure 2.** Avatars - (a) ISU cyclones football player (23,300 polygons), (b) Marching band member (11,300 polygons), (c) Cheerleader (13,300 polygons)

Avatar animation paths were scripted using a waypoint plugin procured from Unity 3D asset store[55]. This system allowed point-to-point animation paths as well as more complex B-Spline free-form curve based paths. Therefore, routines such as marching band walk and dance paths, football player tunnel run and team huddles were all based off scripted waypoint paths. **Figure 3** shows a screen capture of these routines.



**Figure 3.** Waypoint animation – (a) Marching band running into ISU formation, (b) Team huddle formation after tunnel run

### 3.1.6 Framerates

Video games typically employ dynamic frustum culling, where game objects that are not in the field of view of the user are culled and hence not rendered. This improves the interactivity and framerates in the application. However, the user(s) is/are surrounded by screens in the C6 and all objects must be made visible at equal levels of detail. Therefore, frustum-culling techniques cannot be applied, which entailed a performance hit. With framelocking, hardware frame synchronization, network communication of game object updates, and all game elements active in the application, the application executed at about 40 frames per second (FPS) on a standalone workstation, but at 6-7 FPS within the C6. This made the application infeasible for any immersive interaction, despite decimating the avatar geometry on ISU football player geometry by as much as 90%. A few modifications to the application environment helped improve the framerate as described below.

*Football stadium geometry:* Since the application is primarily intended for viewing from within the stadium, objects that were outside of the field of view were deleted. Objects that have significant polygon counts such as railings were replaced by textures wrapped on two triangles. Interior geometry that did not add direct value to the application such as overhead lamps, bar stools, sofas, doors, rooms, etc were deleted from the stadium geometry. In addition, non-essential items such as door handles, knobs, room labels, structural items that are not visible outside were all removed. Also, the

football stadium itself is static and does not have any in-built animations. So, this game object was removed from getReal3D tracking for position and animation updates.

*Avatar geometry:* Different levels of detail were assigned for various avatars depending upon their importance. The football player geometry originally had about 350,000-polygon count. This count, accounting for all 22 players (home and the opposing team), does not nearly cause a significant framerate drop on a standalone workstation. However, avatar animations and transformations resulted in a substantial network traffic overhead in the C6. To keep the interactivity and still highlight the most important aspects of the application, polygon decimation was applied rank ordered as: 1) Football players, 2) Marching band, and 3) Cheerleaders. Therefore, the football players had the highest polygon count, while cheerleaders had the least. Bump and normal maps were generated and applied to make the avatars appear fairly realistic. Figure 2 shows a tally of polygon count for each avatar type used in the application. The football player geometry was decimated by more than 90% of the original 3D model's polygon count.

*Crowd:* Most sports related video games exclusively use sprite animations to simulate crowd. Sprites can effectively convey crowd cheering such as applause, celebrations with one or both arms, booing, etc. We drew inspirations for using sprite animations in the application early on in the project. However, there was a concern that sprites will reduce the immersive experience since a user in the C6 will be able to navigate to any location within the stadium and see the artifacts. So we experimented with using 3D crowd avatars, each weighing about 800 polygons. With just two rows of these 3D crowd models, the application executed at 9 FPS in the C6, although we noticed interactive framerates on a standalone workstation. As a result, the crowd members were reverted back to sprites, textured on two-triangle quadrilaterals. The first few rows of audience in the bleachers was set to one- or two-person sprites (one-person sprites shown in **Figure 4**). All other rows were four- or five-person sprites and lower in detail. Billboarding aligned to the camera view was not applied because the application is generally executed for more than one user in the C6 and only one head tracking system aligned with camera view is available.



**Figure 4.** One-person crowd sprites

Two-dimensional sprites alone did not however create the effect of stadium being filled with audience. While adding more sprites is certainly inexpensive compared to 3D models, they added position and transformation overhead to getReal3D's network communication to the cluster. Therefore, we created the illusion of having a crowd filled stadium by wrapping textures of actual crowd instead of bleachers textures (**Figure 5**).

**Figure 5**a shows that the sprites can hardly be distinguished from the actual crowd texture during aerial view although side view gives away that each sprite member is spaced significantly at a distance from each other, as seen in **Figure 5**b. This minor cheat helped create the illusion that the stadium is fully occupied with audience.
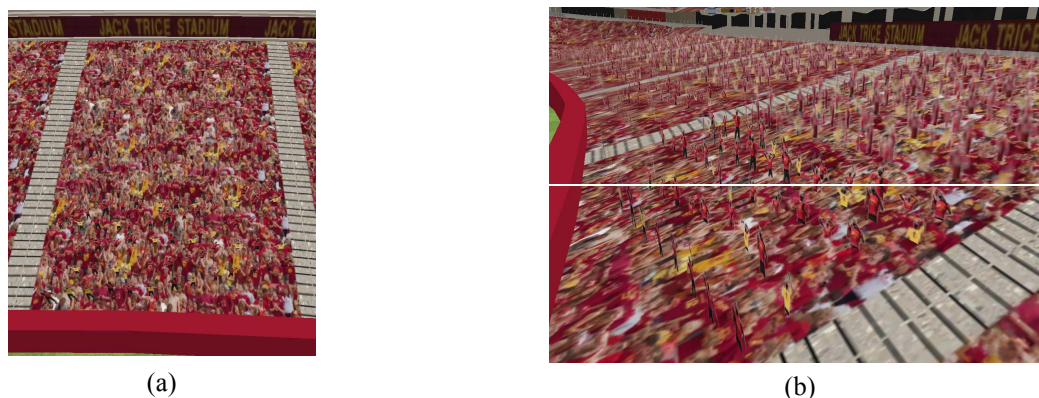


(a)                                                           (b)

**Figure 5.** Sprites on a tiled crowd image in the backdrop (a) Aerial view, (b) Side view

*Scene triggered avatar swaps*: All avatars were not made active simultaneously. The marching band members exit into a building upon completion of their routine, and were then disabled. The football players and cheerleaders were made active only after the marching band was disabled. With a gamepad, a user can switch between marching band scene and the football player tunnel run scene. Therefore, objects were not destroyed but just disabled so the cluster nodes can retrieve and render the objects from memory as and when needed for added interactivity.

*Light sources and shadows:* Although multiple lights and shadows give the most realistic appearance of the gameday experience, realism was sacrificed over performance to a certain degree. Hence, three directional light sources and an ambient light were used in the scene. Although the Oculus Rift version could have benefited by these additional effects, they were not implemented to maintain consistency for user studies. However, these will be implemented for the Rift toward the completion of the project.

These measures improved the framerate to about 18-25 FPS in the C6. While this is not the most interactive, it served a fair tradeoff between quality and performance and rendered it a demonstrable immersive application. While the application executed at about 80 FPS on a standalone desktop workstation, the Oculus Rift version executed at about 60 FPS. **Figure 6** shows pictures of the application being executed in the C6 and the Oculus Rift.



| (a) | (b) |

**Figure 6.** Game-day Unity 3D application in: (a) C6 CAVE, and (b) Oculus Rift

### 3.2  User study

The following section deals with the study composition as approved by the ISU Instructional Review Board, study modes and finally the experimental setup used for the study. A number of experimental technologies were used for the study. The specifications for all technologies are discussed to provide a general idea of the nature of each mode.

#### 3.2.1  Participants

The study consisted of sixty total participants, 15 female and 45 male. Participants in the study ranged from 18 to 35 years of age (Mean, M = 21, Standard deviation, SD = 2.9). Participants were equally divided between the three modes C6, HMD and video. The study was a between subjects design with each participant seeing only their assigned mode. The study lasted around 45 minutes and the participants were compensated $20 (USD) for their time. The pool of participants mainly consisted of undergraduate engineering students at ISU. Participants with known seizure disorders were excluded and those with uncorrected vision were asked not to participant for safety and consistency in results.

#### 3.2.2  Modes

For the C6 and the Oculus Rift modes, game-day events 1 – 5 listed in section 3.1.5 were shown in the order listed to the study participants. In all, the sequence of events took around five minutes of the allotted ten-minute simulation time to complete. These events were triggered on a timer and were not under the participant's control. The hardware specifications for the immersive VR system setup are described in section 3.1.1. The Oculus Rift HMD application was executed for participants on a Dell Precision M4600 series laptop running Windows 7 driven by an Intel Core i7 2.8 GHz processor with 8 GB of RAM. The graphics card running the application was a NVIDIA Quadro 2000M, and the display was extended to a 32" Dell LCD monitor.

For the video mode, a video clip was specifically built and edited from professionally filmed footage provided by the ISU athletics department. The video depicted actual game day footage from previous Cyclone football games in addition to showcasing the traditions and game day atmosphere unique to the campus. The video was shown to participants on the same 32" Dell monitor used for the Oculus Rift HMD portion of the study.

### 3.2.3 Experimental design

The study was a between subjects design. Participants were selected based on the criteria discussed in section 3.2.1. At the start of the study, the participants were brought to the assigned study station (C6, HMD, video). From here, they were asked to fill out an informed consent document and a demographics questionnaire. The demographics questionnaire collected information on participant's age, football experiences, VR experience and Cyclone football attitudes. Then, they were asked to fill out the Witmer and Singer immersive tendencies questionnaire to gauge their tendencies to become immersed in the scene.

When the participant had completed the pre-study forms, they were given instructions for the specific mode they were using. For the video portion of the study, participants were told they would be watching footage from a typical Cyclone football game. For both the HMD and C6 modes, the participants were given instructions on how to navigate the immersive environment using the game pad controller and also to navigate to four prescribed positions on the field from the midfield starting position. Those four positions were as follows: 1) ISU Jack Trice Stadium's side line, 2) center of the ISU team offensive huddle, 3) top of the north end zone scoreboard, and 4) the press box on the west side. These instructions were also displayed within the C6 and the Oculus application as well. The instructions were typed in yellow on an image and texture mapped and distinctly visible, so the participants do not lose track of their required navigational activities for the study. **Figure 7**a and b shows four of the five locations within the application, listed 1 − 4, where these instructions were displayed.
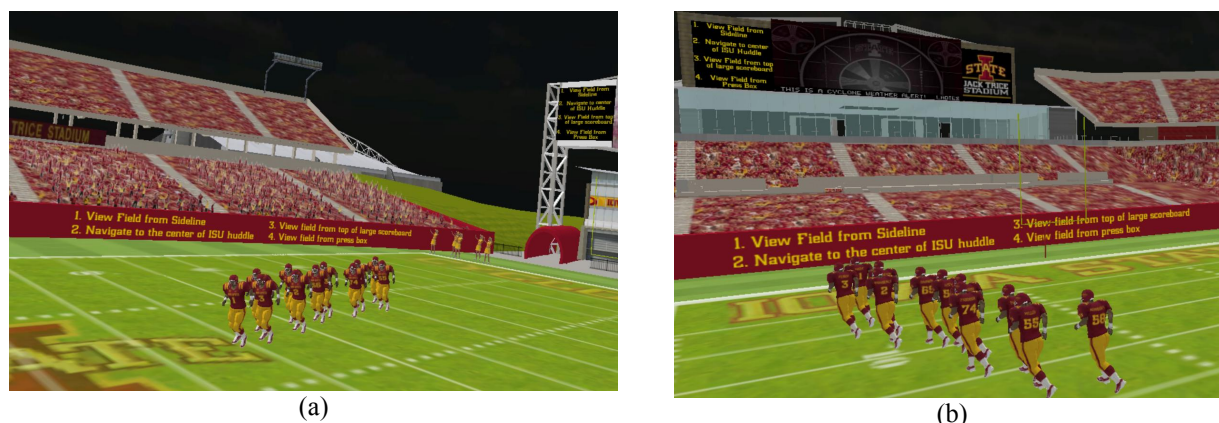


(a)　　　　　　　　　　　　　　　　　　　　　　　　(b)

**Figure 7.** Navigational instructions for participants on the north and south side of Jack Trice Stadium

In an attempt to limit the possibility of motion sickness, especially with the Oculus, the participant's time with the application was limited to ten minutes. Participants were instructed to navigate to the four positions in order. After viewing the field from all four positions they were told they could freely navigate for the remainder of the time. Once a participant's allotted time has run out: a) the video would end, or b) the proctor for Oculus HMD study would indicate to the participant, or c) the proctor for C6 study would open the door to signify the end of the ten minutes.

Once the simulation was complete, the participants were then asked to complete the experience/attention and presence questionnaires. The experience/attention questionnaire was intended to gauge how much information from the simulation the participants retained, and were asked to rate their experience. The presence questionnaire gauged how the participants gauged the believability of the environment.

## 4. RESULTS

*Immersion* and *presence* are both measurable quantities, as described in section 2.1. However, the results presented in this paper are focused towards measuring the difference in perception between the immersive VR in the C6, HMD, and video modes. Hence, *presence* was measured using Witmer and Singer's presence questionnaire. This section details the

types of statistical analysis performed on data collected during the study. It also provides the explicit results from all initial analyses as well as post hoc tests. Lastly, the results will be discussed and conclusions will be drawn as they pertain to the goals of this study.

## 4.1 Presence

In order to analyze the data collected by the Presence Questionnaire (PQ), the questions were divided into six categories: 1) realism, 2) possibility to act, 3) quality of interface, 4) possibility to examine, 5) self-evaluation of performance, and 6) sounds. The reported values in each category were summed for each participant in order to evaluate the category as a whole. The collected data was discrete and not continuous, i.e., non-parametric. Therefore, a series of Kruskal-Wallis H tests[56] were performed with device (i.e., C6, HMD or Video) as the independent variable and the summed categorical PQ scores (i.e., realism, possibility to act, etc.) as the dependent variables. The results showed statistical significance in five of the six PQ categories, as shown in Table 1.

**Table 1.** Kruskal-Wallis test results for each Presence Questionnaire (PQ) category

| Category | Chi-square value, $\chi^2$ | p-value |
|---|---|---|
| Realism | $\chi^2(2) = 7.141$ | p = 0.048 |
| Possibility to act | $\chi^2(2) = 14.425$ | p = 0.001 |
| Possibility to examine | $\chi^2(2) = 17.743$ | p = 0.000 |
| Self-evaluation of performance | $\chi^2(2) = 9.064$ | p = 0.011 |
| Sound | $\chi^2(2) = 7.319$ | p = 0.026 |

Quality of interface was the only category in which no statistically significant difference between device groups was found. Statistical significance was found using $\alpha$ value of 0.05. The prevalence of statistical significance in the data indicates that there are notable differences in the ability of the different devices to create an environment that allows the user to feel like they are really experiencing the stadium on game day. This information indicates that we may continue to explore these differences in the post hoc examination.

## 4.2 Post Hoc Examination

A sequential post hoc examination using Dunn's[57] procedure with a Bonferroni correction[58] for multiple comparisons was used to evaluate the five PQ categories in which statistically significant differences were found. Adjusted p-values are presented.

In the realism category, the post hoc analysis revealed statistically significant differences in median realism scores between the C6 (M = 28.00) and HMD (M = 22.50) (p = 0.046) device groups, but not between any other group combinations. This indicates that the users felt that the C6 induced a higher sense of realism than the HMD. It can be concluded that this distinction is a result of the difference in hardware used because both of the VR groups viewed the same simulation. One factor that may have contributed to the higher ranking of the C6 is its superior resolution and more immersive technology. However, this superior technology comes with a much higher cost. The next step is to decide if the advantages of the CAVE technology are worth the cost.

In the Possibility to act category, the post hoc analysis revealed statistically significant differences in median possibility to act scores between the video (M = 7.00) and C6 (M = 11.00) (p = 0.001), and the video and HMD (M = 10.00) (p = 0.014) device groups, but not between the C6 and HMD groups. These results can be seen when comparing medians in the boxplot in **Figure 8**a. The plots show that the median values for both the HMD and C6 modes are noticeably greater than that of the video. From these results, one can conclude that the HMD and the C6 allow the user to interact with the stadium environment equally, while the video mode inhibits the user's ability to interact with the environment. This difference was to be expected, as the user obviously cannot manipulate his/her location or movement when watching a video. However, no difference was found between the C6 and HMD modes in this category making both viable candidates for use in football recruitment.
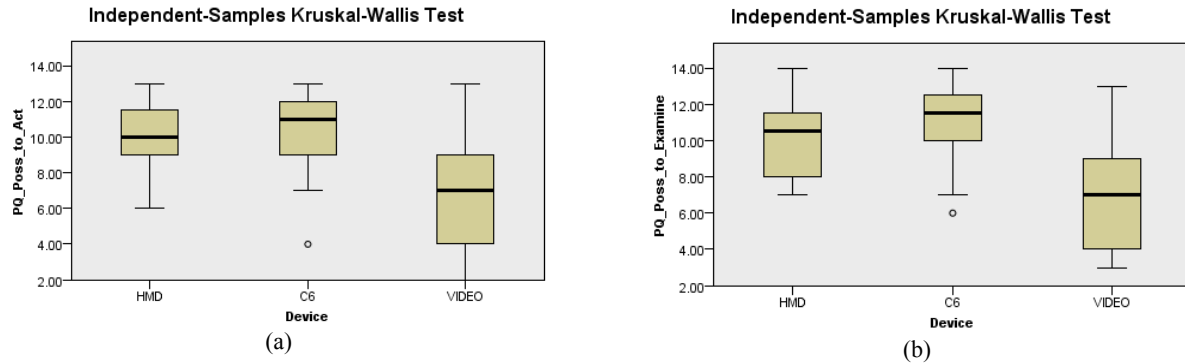
**Figure 8.** Boxplot comparison of median possibility for PQ categories: (a) Possibility to act, (b) Possibility to examine

In the possibility to examine category, the post hoc analysis revealed statistically significant differences in median possibility to examine scores between the video (M = 7.00) and C6 (M = 11.50) (p = 0.000), and the video and HMD (M = 10.50) (p = 0.015) device groups, but not between the C6 and HMD groups. These results can be visually verified by examining the box plots in **Figure 8**b. Similarly to the previous category, these results show that the C6 and HMD equally allow the user to examine their surroundings, while the video mode does not. This was expected, because the video mode does not allow the user to control their movement or position. The fleeting nature of the video clips in the recruitment video could also contribute this deficiency. However, it is promising, for recruitment purposes, that the C6 and HMD both performed well in this category. The results show the game day application, independent of platform, provides the user the opportunity to more completely examine and get a feel for their surroundings. This added examination ability is very advantageous to a recruiting department attempting to show off unique aspects of their facility.

In the self-evaluation of performance category, the post hoc analysis revealed statistically significant differences in median self-evaluation of performance scores between the video (M = 6.50) and HMD (M = 4.00) (p = 0.008) device groups, but not between any other combinations of groups. These results show that users felt they performed tasks better in the video mode than users in either of the VR modes. Users of the video mode likely felt they performed better because they were not asked to perform any tasks. However, those who used the C6 and Video devices were asked to navigate to specific locations in the stadium. We may exclude the video mode from this category of the PQ because there was no tasks asked of those who watched the video. We may also conclude that no difference was found in the self-evaluation of performance category between the HMD and C6 modes. This means that users were equally satisfied with their performance whether they were using the HMD or the C6.

In the sounds category, the post hoc analysis revealed statistically significant differences in median sound scores between the video (M = 18.00) and C6 (M = 15.50) (p = 0.000) device groups, but not between any other combinations of groups. These results indicate that users preferred listening to the sound used in the video than those used in the HMD mode. Since both of these modes used the same headphones to deliver sound, we can conclude that the users felt that the sounds of the video were more realistic, this could be because this audio was professionally compiled, while the audio used in the VR environment was programmed/scripted.

### 4.3 Discussion

Results of the post hoc examination indicate that both the HMD and C6 modes provide a superior ability to interact with and examine the virtual game day stadium when compared to the video. This factor is important because this affords football recruits the unique experience of getting up close and personal with the stadium without ever setting foot on the field. The ability of both VR modes to provide this experience is remarkable because it shows that the lower cost HMD is viable substitute for the extremely expensive and immobile C6. However, the higher ranking of the C6 in the category of realism shows that the C6 still has some advantages over the HMD. The only category in which the video was ranked higher was sound. However, the quality of the sound in the VR simulation can be easily improved, again showing the HMD could be a valuable tool in football recruitment.

# 5. CONCLUSIONS AND FUTURE WORK

Overall, the research challenges identified in section 2.3 are addressed and goals achieved. A virtual reality application of the Iowa State Cyclone game-day experience was developed. They were implemented on two platforms: a) high-end 48-node immersive C6 VR system, and b) portable low-end Oculus Rift HMD. While the developed application performed at about 18-25 FPS in the C6, framerates of about 50-60 was observed within the HMD. Network communication and synchronization of various objects in the application and their states across the cluster per frame was attributed to a lower framerate within the C6. The HMD implementation did not suffer from these pitfalls because only one host computer generated the rendered output. While this project is still a work in progress at the time of writing, we fully anticipate further performance improvements.

On the other hand, results from the user study conducted indicate that the virtual game day application significantly improved upon the standard video mode. Results also indicate that both the C6 and the HMD mode produce similar results for various immersion and presence categories. The C6 enhanced the feeling of being present in the Jack Trice stadium as evident from higher realism scores. However, the narrow differences in results on other categories indicate that the low-cost HMD version can be a formidable competitor to an expensive immersive VR system. It is hence a statistically reasonable conclusion that a low-cost portable version of the game day experience, compared to the C6, allows reaching out to a larger number of recruits without a significant tradeoff in overall experience. By using the application the recruiting team at ISU garnered the ability to showoff the unique aspects of Iowa State Cyclone football, hopefully laying down the foundation of future program success in years to come.

In the future, the authors would like to gain an understanding of how the application compares to the actual game day experience. Due to the time of year development took place the authors were not able to study how participants of an actual football game responded to the questionnaires. Now that the study is approved and designed, the authors would like to give questionnaires from the study to attendees of actual football games and study how the application compares to the true game day experience. This will provide valuable insight into the accuracy of the application not just in relation to the standard video mode but to the actual experience as well.

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