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# Investigation of Dynamic View Expansion for Head-Mounted Displays with Head Tracking in Virtual Environments

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**Abstract**

*Head mounted displays (HMD) are widely used for visual immersion in virtual reality (VR) systems. It is acknowledged that the narrow field of view (FOV) for most HMD models is the leading cause of insufficient quality of immersion, resulting in suboptimal user performance in various tasks in VR and early fatigue, too. Proposed solutions to this problem range from hardware-based approaches to software enhancements of the viewing process. There exist three major techniques of view expansion; minification or rendering graphics with a larger FOV than the display's FOV, motion amplification or amplifying user head rotation aiming to provide accelerated access to peripheral vision during wide sweeping head movements, and diverging left and right virtual cameras outwards in order to increase the combined binocular FOV. Static view expansion has been reported to increase user efficiency in search and navigation tasks, however the effectiveness of dynamic view expansion is not yet well understood. When applied, view expansion techniques modify the natural viewing process and alter familiar user reflex-response loops, which may result in motion sickness and poor user performance. Thus, it is vital to evaluate dynamic view expansion techniques in terms of task effectiveness and user workload. This paper details dynamic view expansion techniques, experimental settings and findings of the user study. In the user study, we investigate three view expansion techniques, applying them dynamically based on user behaviors. We evaluate the effectiveness of these methods quantitatively, by measuring and comparing user performance and user workload in a target search task. Also, we collect and compare qualitative feedback from the subjects in the experiment. Experimental results show that certain levels of minification and motion amplification increase performance by 8.2% and 6.0%, respectively, with comparable or even decreased subjective workload.*

Categories and Subject Descriptors (according to ACM CCS): H.5.1 [Computer Graphics]: Multimedia Information Systems—Artificial, augmented, and virtual realities

## 1. Introduction

Head mounted displays (HMDs) have been used to achieve visual immersion since the earliest days of virtual reality (VR) and augmented reality (AR) systems. Many modern HMDs are equipped with orientation sensors for tracking user head rotation and refreshing the virtual environment (VE) based on the measurement (e.g., Oculus Rift HMD [Ocu12]). Due to hardware limitations, the field of view (FOV) of most HMD models does not exceed 60 degrees per eye, whereas human natural FOV is over 180 degrees horizontally. There exist custom-built and prototype HMD models with ultra-wide panoramic viewing field [Art00], however, they are not yet common. Using HMDs with a narrow field of view inevitably results in user inconvenience.

Achieving a realistic, life-like viewing experience in virtual environments has been a subject of active research. One approach is simply to use special hardware to widen the FOV [Art00]. However, such wide FOV HMDs tend to be bulky, heavy and uncomfortable. For user acceptance, a lightweight small HMD is often more preferable. Another approach involves expanding view in software, for instance, by minification. Minification is a common rendering technique that renders graphics with a larger FOV than that of the display device. A non-linear minification has also been proposed [NYY04]. However, this method permanently widens the FOV during the entire session in VE, even when users do not need such a wide view, e.g., when performing close-range direct object manipulation tasks. Therefore, dynamic

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view modifications, driven by the current user needs seems as a desirable and useful improvement of known view expansion techniques. As of this writing, there are very few published studies on dynamic view expansion.

It is a common practice in VE to project real user head motion onto virtual camera position and orientation, providing the true first person view for the immersed user. The head motion is captured by 6 or 3 degrees of freedom (DOF) head tracker, which is often integrated into an HMD design. In this study, we aim to associate dynamic view expansion with continuously updated information of head orientation in VE. Among many conceivable ways, we have implemented and evaluated three techniques for dynamic view expansion, that will be discussed in details later.

Also, while aiming to improve task performance, one needs to do so without increasing user workload, which may cause users to develop fatigue and/or VR sickness. These conditions, in turn, may result in inferior performance and even refusal to continue the mission. Thus, in our investigation of view expansion techniques, we carefully evaluate not only task performance but also VR sickness and workload.

## 2. Related work

Arthur studied the impact of FOV on user performance in VR, using a super-wide FOV Kaiser HMD [Art00]. He demonstrated experimentally that a wide horizontal field of view has positive effects on searching, spatial awareness and other types of tasks and conditions. Overall, it can be said that a wide FOV increases user task performance in VE.

Minification is a common practice in VR when the user needs to see a larger FOV than the that of the display. Because of the compressed view, it also has a significant impact on distance judgement [ZNWK]. Nagahara et al. [NYY04] investigated effectiveness of static minification, using a large dome screen display, CYLINDA. This study compares user performance under three conditions; no view expansion, linear view expansion and nonlinear view expansion, in tasks that require navigation with obstacles present. The results show that nonlinear view expansion is the most effective, in both real and virtual environments.

Ardouin et al. [ALM*12] developed a 360 degree HMD named FlyVIZ that displays 360 degree images produced by a panoramic camera. This HMD makes it possible for users to catch a stick behind their back and dodge a ball thrown from behind. However, such a special HMD is not widely available. More importantly, users wearing FlyVIZ are deprived of sense of distance, and given a false sense of orientation, because the panoramic image is monocular and compressed into a narrow FOV (45 degrees horizontal) of the HMD. In this system, view expansion remains in effect all the time so that the effectiveness of dynamic view expansion is unknown.

Sherstyuk et al. [STG12] suggested to reduce the inconvenience of narrow FOV HMDs, by introducing “Predator-prey vision metaphor.” This metaphor employs changing virtual camera parameters dynamically, driven by the current user task and viewing conditions. In the “predator” mode, cameras are converging on a close-range target, as it happens in real life when a predator is chasing a prey, and good stereo perception and sense of distance are of utmost importance. Conversely, in the “prey” mode, priority is given to a wider viewing area, at the expense of reduced stereo overlap from both cameras. In the prey mode, the left and right cameras are allowed to diverge sideways temporarily, increasing the size of peripheral vision. Confirming the efficacy of this metaphor, Sherstyuk et al. [SDS12] conducted an experimental study on dynamic camera convergence (“Predator vision”). Participants were asked to catch as many virtual butterflies as possible, using their virtual hand in VE. Both the user head and the hand were tracked in 6 DOF. The results show that dynamic eye convergence increases catching success rate and decreased hand fatigue. The authors did not use camera divergence (“Prey vision”), as there were plenty of butterflies visible in direct view.

Jay et al. proposed another method to achieve view expansion [JH03], who employed amplified head rotation for that purpose. In their system, the virtual camera was rotating faster than the user head, effectively forcing the peripheral vision content into the viewable central vision area, while the head was in motion. The researchers proved experimentally that their method is effective for visual search tasks in VE. The participants also reported that the “accelerated” camera controls feel more natural to them, than conventional direct head motion transfer. However, there was no means of turning amplification of head rotation off. As a result, the system could not accommodate tasks that involve direct object handling, because virtual hands cannot be accelerated in the same way as the head. In addition, this system was restricted to 1D rotation about single Y-axis. Amplification of an arbitrary 3D rotation violates nulling and directional compliances and should be avoided in user interfaces, as discussed by Poupyrev et al. [PWF00]. A similar system with 1D-amplified rotation about X-axis was presented by Bolte et al. [BBS*10].

As mentioned above, super-wide FOV HMDs are effective in surround search tasks [Art00], but users must be trained before they can use such systems. Panoramic and nearly-panoramic HMDs tend to be bulky, heavy and uncomfortable, making them impractical for many applications. Static view expansion, in contrast, allows users to increase their performance in navigation tasks [NYY04], even if the viewable area is the same. It is reasonable to expect that view expansion will be effective to other types of tasks in VE as well. Dynamic view modification has been proved effective in real-time camera convergence (“Predator vision”) [SDS12]. Additionally, it has been shown that continuous view expansion is effective in search tasks [JH03]. However, little has been reported on the effectiveness of dynamic view expansion, triggered by the current user task and viewing conditions. Thus, we set it as the goal of this study; to measure and analyze effects of view expansion techniques, dynamically applied in HMD-based virtual environments.

## 3. Design principles of view expansion suitable for VE with HMD

In this section, we propose one possible VR application, where view expansion techniques may be particularly effective and useful. Also, we put forward a number of design guidelines for our view expansion system, focusing on the suggested scenario.

### 3.1. View expansion for training in VR

There are many training applications, both civil and military, that are well suited for VR implementation, where trainees are immersed into VE with an HMD. We will use a variation of a VR-Triage scenario, which is described below.

Trainees will be immersed into a virtual battleground or a disaster area, as a medical team, in order to perform triage of human casualties. Virtual victims will be scattered in the VE, and trainees will be required to locate, approach and medically examine them all. This mission will require extensive wide-area search and close-range direct object manipulation tasks. Advanced training scenarios may include various hazardous elements, such as enemy troops, fire, or collapsing rubble. Users must be able to notice such elements, and take action immediately, for example, protect themselves. We hypothesize that view expansion techniques will help users notice such dangerous conditions sooner and complete their missions with fewer mistakes or penalty points. Thus, for our study, we design VE simulating presence of enemy troops that must be detected and defeated timely. The task details will be described in Section 5.

### 3.2. Target hardware

The design principles regarding target hardware are as follows:

**Stereo HMDs:** The system needs to be compatible with a variety of stereo HMDs that are currently available on the market. The standard HMD specifications, such as FOV, the angle of stereo overlap etc., must be parsed and understood by the view expansion control system.

**Fixed display units:** The system does not need to move a display unit or change its stereo overlap physically and dynamically. Instead, an HMD with fixed display units and a fixed stereo overlap should be supported. View expansion is realized if we can move display units and change the stereo overlap, however, few HMD models support such mechanisms. View expansion should be achieved in a software approach.

**Motion sensor:** The system needs to be equipped with a 6-DOF or 3-DOF motion sensor for head tracking. At least, head orientation must be tracked.

### 3.3. View expansion policies

The design principles regarding the view expansion mechanism are as follows:

**Search tasks only:** According to the assumed training scenario, users will have to switch tasks between wide-range visual search and close-range object handling frequently. View expansion is expected to help with the visual search, but it will likely to interfere with users' ability to perform manipulating tasks, because it disrupts convenient viewing patterns and will have a negative impact on distance perception. Therefore, view expansion should be applied dynamically on-demand, only when the user is performing a search task.

**Automatic activation:** The easiest way to ensure to activate and deactivate view expansion on-demand is to let the user do it, by a dedicated input device (i.e., a button on a joystick). Obviously, this is a poor design decision which puts an additional burden on users under a stressful situation. Moreover, such a design may require "clutching," when users are forced to interrupt their current activity, use an additional device (a button), and then return to the original task. Clutching is known to degrade user performance and should be avoided. Thus, the control system needs to start and stop view expansion automatically, by watching and analyzing user behaviors.

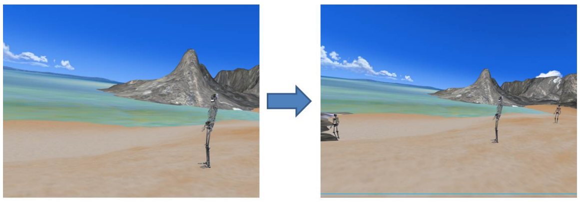
**Stress-free:** In realistic training scenarios, users will be required to spend significant amount of time on the mission. The duration when view expansion is in effect may span several minutes. If users feel overstressed by view expansion, it will have a negative impact on their performance. Therefore, view expansion must be stress-free as possible even if applied for a considerable time, e.g., one minute.

## 4. View expansion techniques

In this section, we classify three view expansion techniques and discuss their advantages and disadvantages.

### 4.1. Widening

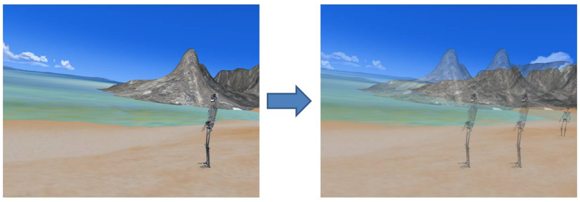
Minification, or rendering graphics in a larger FOV than the display FOV is a common technique in VR. Hereinafter, we will refer to this technique as *widening*. With widening, view will zoom out, as shown in the right side of Figure 1. Figure 1 shows a beach scene with enemy characters represented by human skeletons. There are total three skeletons in this scene, but only one is visible in "Normal" view. Widening makes the objects look smaller than normal, but presents more information in wider viewing angle. In the case of Figure 1 (right), all three enemies are now within the view. This indicates that users can search for a target more efficiently.



Normal

Widening

**Figure 1:** *View changing from Normal to Widening.*



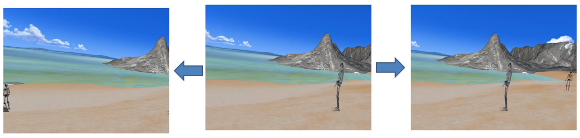
Normal

Diverging

**Figure 3:** *View changing from Normal to Diverging.*

### 4.2. Shifting

Motion amplification is another common technique in VR to show more information in the periphery to the direction the user is moving to. One of such methods has been proposed by Jay et al. [JH03]. Users' virtual eyes move more to the right than the direction of the display unit when they turn right, and move more to the left when they turn left. Thus, their combined body-head-eye rotation allows users to search the scene much faster than if they were confined to head movements only. Hereinafter, we will refer to this technique as *Shifting*. Thanks to shifting, users can notice targets quicker. Figure 2 shows view changing by the shifting technique. The center image of Figure 2 shows a normal view, whereas the right and left images show the views when users are turning to the right and the left, respectively.



Shifting(right)

Normal

Shifting(left)

**Figure 2:** *View changing from Normal to Shifting.*

### 4.3. Diverging

Diverging corresponds to "Prey vision" in "Predator-prey vision metaphor," proposed by Sherstyuk et al. [STG12]. This method makes use of decreasing stereo overlap and extending the total binocular FOV. Normally, human eyes are looking ahead in approximately parallel directions, but virtual cameras can diverge outwards. When that happens, users' view looks as shown in Figure 3 (right). With diverging cameras, users will lose their stereopsis and the view becomes diplopic (double-vision). As a trade-off, viewers now can see the second enemy that appears in the far right side of the second image ("Diverging"), which was not visible in the "Normal" view. This suggests that users will possibly be able to find targets more efficiently.

### 4.4. View expansion parameters

This study aims to compare all three view expansion techniques explained above at once in a unified experimental setup. Users are likely to move their head faster when they are searching for a target, which can be roughly detected by analyzing the head rotation speed. We have two parameters to describe the behavior of our view expansion mechanism. First parameter is the minimum head rotation speed to activate view expansion. If view expansion is too sensitive to the head rotation speed, the view will change very frequently, causing confusion. So view expansion is activated only when the head rotation speed exceeds a certain threshold. Second parameter is the upper limit of the degree of view expansion. The degree of view expansion increases linearly, according to the head rotation speed. However excessive expansion is likely to distract users from their tasks. So the degree of expansion stays the same when it exceeds a certain threshold. The view returns to the normal condition, after a certain delay, when view expansion is deactivated.

## 5. Experiment

In this section, we describe the experimental study on the effectiveness of dynamic view expansion techniques.

### 5.1. Prototype system

A prototype system was built for the experiment. An Oculus Rift headset was used as a stereo HMD [Ocu12], which features a wide FOV (110 degrees diagonal and 90 degrees horizontal) and a high speed (1000Hz) head tracker. The three view expansion techniques described in Section 4 were implemented in Flatland, an open source 3D engine [Fla02]. Flatland provides enough flexibility in tweaking the FOV and rendering regions which is required to conduct the experiment. Figure 4 shows a subject performing the experimental task. The system was installed on a single Ubuntu Linux PC. The 3D content was rendered with OpenGL API at 30 frames per second. The head rotation speeds to trigger and saturate view expansion were set to 30 and 120 degrees per second, respectively.

### 5.2. Experimental task

A task is designed to evaluate how effectively subjects can find targets in different conditions. They are asked to wear the HMD and spend five minutes on a virtual beach, finding and shooting enemies, represented by human skeletons.

**Figure 4:** *A subject performing the experimental task.*

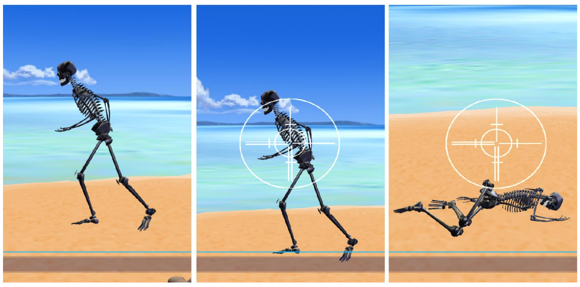


**Figure 5:** *Target detection and elimination.*

Figure 5 shows three screenshots of the virtual scene, with a moving target. They are 180 cm tall and 50 cm wide. When subjects find a target, they indicate the detection by continuously staring at the target for one second. The staring scope is a 12-degree wide circle at the center of the view (Figure 5, center). After being stared at for more than 0.5 seconds, the target turns red, so that subjects can notice that they have captured the target. After being "under fire" for more than one second, the target falls down and "dies" (Figure 5, right). This action signifies that the target is defeated. The defeated target remains lifeless for three seconds. After that, it reappears in a random direction 6 meters away from the subject. At any given time, there are at maximum three targets on the field. When a target remains undetected for 15 seconds, it is regarded as missed. Missed targets teleport to a new location, after a three second delay, and the mission continues.

The experimental scene was purposefully set to be simple, to avoid overloading subjects with distractors. The targets were animated by real human walking and running motions, captured with Flock of Birds and fit to rigged 3D models in Autodesk Maya. We carefully balanced the task load to make the sessions reasonably challenging but not too hard.

### 5.3. Compared conditions

There are two independent variables; the view expansion condition and the native FOV of the HMD. Following seven conditions of view expansion were compared. Two values for the View expansion degree were determined for each technique empirically in pilot studies in advance of the experiment.

- None (No expansion)
- Widening Small (20 deg)
- Widening Large (40 deg)
- Shifting Small (10 deg)
- Shifting Large (20 deg)
- Diverging Small (7.5 deg)
- Diverging Large (15 deg)

The native FOV of the HMD had following two sets of values. The smaller FOV is simply realized by masking the outer region by black pixels.

- Horizontal 90 deg, Vertical 112.5 deg (Standard FOV)
- Horizontal 30 deg, Vertical 22.5 deg (Restricted FOV)

The experiment was designed as a within-subject study, so each participant performed the task 14 times. The order of conditions was counterbalanced by Latin Square pattern. 28 healthy volunteers, with normal or corrected to normal vision, were invited to participate, 14 males and 14 females. Their mean age was 24.24 years (SD 3.80). After brief instructions, participants were offered some time to practice the target detecting procedures, before the actual experiment began. During sessions, the number of targets detected and the amount of head rotation were recorded. Each session lasted for five minutes.

Immediately after each session, the condition details were explained to users and they were asked to complete a questionnaire about their experience, see Table 1. The answers to questions A and B were given on a 0-10 Likert scale; 0 means "strongly disagree" and 10 means "strongly agree." Participants' workload was measured by NASA-TLX [HS88], a subjective workload assessment tool.

**Table 1:** *Post-session questionnaire.*

| | |
|---|---|
| Q.A | During head turns, viewing felt natural |
| Q.B | After the experiment, I felt dizzy |
| | Workload by NASA-TLX [HS88] |

### 5.4. Hypotheses

Expected effects of the dynamic view expansion techniques can be summarized as following hypotheses.

**H1:** Dynamic view expansion will increase search performance with properly configured parameters.
**H2:** Dynamic view expansion will decrease search performance with excessive degree of expansion.
**H3:** Dynamic view expansion will decrease user comfort in roughly proportion to the degree of expansion.

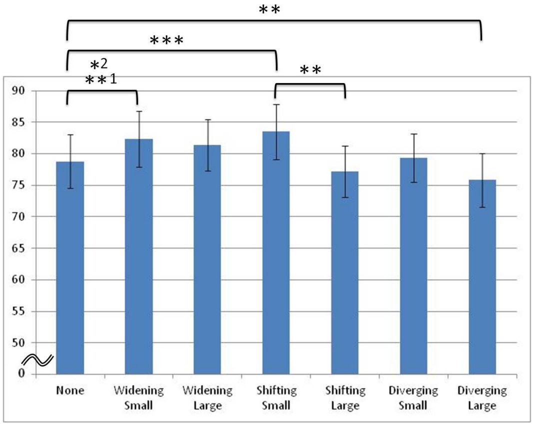


**Figure 6:** *Number of detected targets.* [1] *Significant only for the 90 deg native FOV.* [2] *Significant only for male subjects.*

**H4:** Significant performance gain is obtainable with negligible or acceptable decrease in user comfort, by properly configuring expansion parameters. To confirm that such a set of parameters exists and to determine the amount of performance gain is a major objective of the experiment.

**H5:** Degree of effects will be different for different dynamic view expansion techniques. Diverging and widening techniques are fundamentally different from normal viewing experiences, whereas shifting is close to natural human practice. So it is reasonable to expect that they will cause a more noticeable increase in stress and workload than shifting. In the same sense, diverging will increase stress and workload most quickly as we never have such a viewing experience in the real life.

## 6. Results

In the following, we report the experimental results and the effectiveness of each view expansion technique. We have conducted a two-way ANOVA and applied Shaffer's Modified Sequentially Rejective Bonferroni procedure [Sha86], when necessary.

### 6.1. Detected targets

Figure 6 shows average numbers of detected targets per five-minute session. A single, double and triple asterisks indicate $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively. The effectiveness of each view expansion technique is described below.

**Widening:** Widening Small condition significantly increased the number of detected targets compared to None condition, when the native horizontal FOV was 90 ($p < 0.01$) or when subjects were male ($p < 0.05$). No significant difference was found for the 30 deg native FOV or for female subjects. This is probably because that view expansion in Widening Small condition was already too large to be comfortable for subjects. No significant difference was found between Widening Large and None conditions.

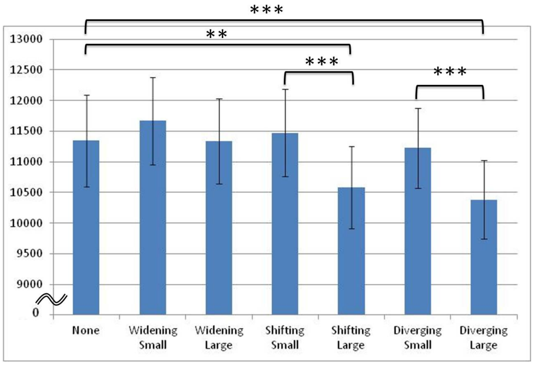


**Figure 7:** *Accumulated head rotation in degree.*

**Shifting:** Shifting Small condition significantly increased the number of detected targets compared to None condition ($p < 0.001$). However, the number of detected targets is decreased in Shifting Large condition compared to that in Shifting Small condition ($p < 0.01$). The amount of motion amplification in Shifting Large condition appears to be too large, resulting in the degraded performance.

**Diverging:** The number of detected targets in Diverging Large condition was significantly less than that in None condition ($p < 0.01$). Apparently, views in this condition were too confusing and highly diplopic, making them unacceptable for human eyes. No significant difference was found between Diverging Small and None conditions.

### 6.2. Head rotation

Figure 7 shows average accumulated head rotation in degree per session. The effectiveness of each view expansion technique is described below.

**Widening:** No significant difference was observed between None and Widening conditions, so it seems that Widening technique has little impact on user head rotation.

**Shifting:** Head rotation under Shifting Large condition was significantly less than those in Diverging Small ($p < 0.001$) and None ($p < 0.01$) conditions. No significant difference was found between Shifting Small and None conditions. These results show that, with Shifting techniques, comparable search performance was achieved with reduced head rotation (Shifting Large) and better search performance was achieved with comparable head rotation (Shifting Small).

**Diverging:** Head rotation in Diverging Large condition was less than those in Diverging Small and None conditions ($p < 0.001$). This indicates that excessive view expansion with Diverging techniques restrains subjects' head rotation.

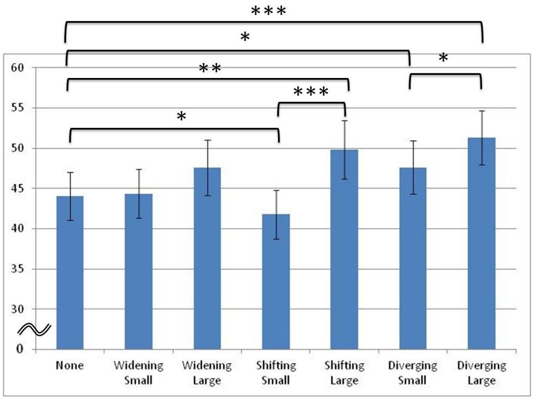


**Figure 8:** *Workload indices by NASA-TLX.*

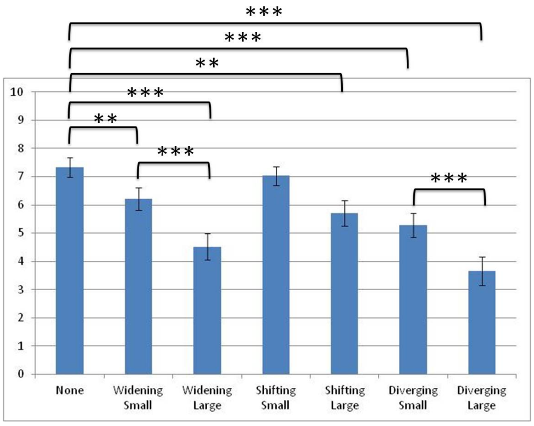


**Figure 9:** *Ratings for Q.A "Naturalness of viewing."*

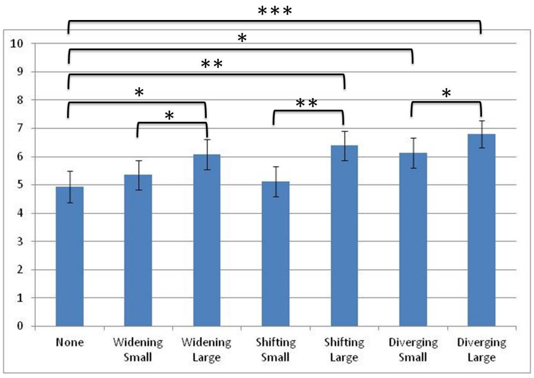


**Figure 10:** *Ratings for Q.B "dizziness."*

### 6.3. Workload

Figure 8 shows average workload indices measured by NASA-TLX. The effectiveness of each view expansion technique is described below.

**Widening:** No significant difference was found between Widening and None conditions. It seems that Widening techniques had little or no impact on user workload.

**Shifting:** Shifting Small condition significantly decreased the participants' workload compared to None condition ($p < 0.05$). In contrast, Shifting Large condition significantly increased participants' workload ($p < 0.01$), due presumably to excessive rotational motion amplification.

**Diverging:** Diverging Small condition increased participants' workload ($p < 0.05$). Diverging Large condition further increased the workload significantly than that in Diverging Small condition ($p < 0.05$). These results show that Diverging conditions are more physical and/or mentally demanding than the normal condition.

### 6.4. Naturalness of viewing

Figure 9 shows subjects' average ratings for Q.A.

**Widening:** Widening Small condition significantly decreased subjective naturalness of viewing ($p < 0.01$). Diverging Large condition decreased it further when compared to Widening Small condition ($p < 0.001$). In Widening conditions, the entire scene appeared smaller and degraded naturalness of viewing.

**Shifting:** Shifting Large condition significantly decreased subjective naturalness of viewing ($p < 0.01$). In contrast, no significant difference was found between Shifting Small and None conditions.

**Diverging:** Diverging Small condition significantly decreased subjective naturalness of viewing ($p < 0.001$). Diverging Large condition decreased it further when compared to Diverging Small condition.

The results in Shifting conditions confirm the earlier findings reported by Jay et al. [JH03]. In the study, they observed that, with properly chosen values, amplified head rotation was appreciated by users more than the standard camera rotation, which many users found to be annoyingly slow. In our results, Shifting Small condition received the highest rating among all techniques compared, which partially corroborates the study by Jay et al. [JH03].

### 6.5. Dizziness

Figure 10 shows subjects' average ratings for Q.B.

**Widening:** Widening Large condition significantly increased subjective level of dizziness compared to that in None condition ($p < 0.01$). In contrast, no significant difference was found between Widening Small and None conditions.

**Shifting:** Shifting Large condition significantly increased subjective level of dizziness compared to that in None condition ($p < 0.01$). In contrast, no significant difference was found between Shifting Small and None conditions.

**Diverging:** Diverging Small condition significantly increased subjective level of dizziness compared to that in None condition ($p < 0.05$). Diverging Large condition increased the dizziness further compared to Diverging Small condition ($p < 0.05$).

### 6.6. Discussion

**H1** and **H2** have been supported for Widening and Shifting techniques. The experimental results indicate that with proper adjustments of control parameters, Shifting and Widening techniques increase user performance in search tasks. However, it was not the case for Diverging techniques. The degree of expansion in Diverging Small (7.5 degrees) may have been already too large. Additionally, our results show that excessive view expansion degrades user performance in Shifting and Diverging conditions. Widening techniques with an excessive degree of expansion is less harmful to search performance.

The fact that view expansion has a measurable effect on the amount of head rotation is open for interpretations. This may be an indication that participants felt very dizzy and tired and tried to avoid any extra activities. Alternatively, reduced amount of head rotation may signify that view expansion provided enough means to view the scene with minimal physical efforts, allowing users to conserve their movements. At this moment, we cannot prove either hypothesis.

**H3** has been partially supported. Subjective evaluations became worse with increased degrees of view expansion. However, user workload did not increase in Widening condition and even decreased in Shifting condition. Similar results can be seen for subjective naturalness of viewing and dizziness. It is remarkable that search performance were increased in these conditions where the user workload did not significantly increase compared to the normal condition. Thus, **H4** has been supported for Widening and Shifting techniques. This finding is very valuable from the practical standpoint, for user interface design purposes. From the observations above, **H5** has naturally been supported.

## 7. Conclusion

Although static view expansion techniques are proven to be effective in mitigating the problems related to narrow FOV HMDs, little has been reported on dynamic view expansion. Dynamic view expansion provides natural standard viewing normally and a wider, modified view when necessary. In our implementation, this is achieved by activating and deactivating view expansion based on user head rotation speed.

In the present study, we have studied and evaluated the effectiveness of a few dynamic view expansion techniques and their impact on user performance and overall experience in VE. Specifically, we compared three techniques; *widening* the rendering FOV (commonly known as minification), *shifting* the view according to users' head rotation (rotational motion amplification), and *diverging* virtual cameras outwards. Our findings show that with proper configuration, Widening and Shifting techniques increase user's performance in a target search task without increasing user workload. It was also found that excessive view expansion increases users' workload and decreases performance.

Future work include conducting follow-up studies to optimize control parameters, to investigate the effectiveness of combined techniques, and to explore the potential of dynamic view expansion in video see-through augmented reality.

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