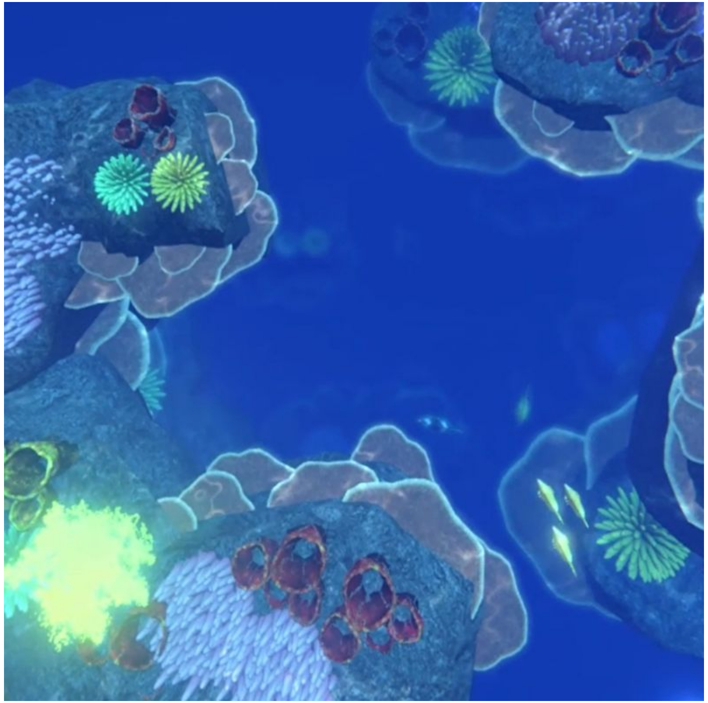
# **Design and Evaluation of ProneVR:** Constraint-Aware Interaction for Prone-Position Immersive Virtual Reality



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VIDi Lab Presentation
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# **Background:** Procedural Pain & Anxiety

- Acute procedural pain and anxiety are common during medical procedures (Teh et al., 2024)
  → **motivates real-time management during care**
- Current clinical practice historically relies on pharmacological approaches

**Sedatives**

- Diazepam
- Propofol

**Opioids**

- Hydromorphone
- Morphine
- Fentanyl

# **Background:** Pharmacologic Limitations

- Pharmacologic approaches introduce challenges:
  - Safety & monitoring complexity
  - Variable patient response and side effects
  - Risk of long-term opioid exposure
- Increased clinical resource utilization (monitoring, staffing, equipment)

*(e.g., Teh et al., 2024)*

# **Background:** Pharmacologic Limitations

- Pain experience is not purely physiological

  ⇒ Strongly influenced by attention, emotion, and perception
  *(Shaygan et al., 2016)*

- **Motivates demand for non-pharmacological, perception-driven intervention**

# **Background:** Static Visual Pain Relief

Pain perception can be modulated by **simple visual input** (Vincent et al., 2010; Shaygan et al., 2017).

- Early work shows that **static 2D images** influence pain through **emotional engagement and attention**, not sensory blocking.
- These interventions operate within the **normal visual field** and require no specialized hardware.

Vincent et al. (2010)

**Limitation:** Prior environmental preparation, limited disengagement from clinical room

# **Background:** Static Visual Pain Relief

- Previous studies show visual content can change pain experience; studies manipulate pleasure, receptiveness, and attention load (e.g. Shaygan et. al., 2017)

**Case Study:**

- Study used multiple photographs across various domains
- Viewing “loved-ones” significantly reduced pain unpleasantness compared to other control conditions (e.g. strangers and neutral images).

| | Picture | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Loved Ones | | Strangers | | Landscapes | | Optical Illusions | |
| Variable | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Valence* | 8.50 | 1.39 | 6.33 | 2.00 | 7.56 | 2.02 | 6.29 | 2.00 |
| Arousal† | 6.66 | 2.54 | 7.75 | 1.78 | 7.84 | 1.59 | 6.53 | 2.05 |

*Valence ratings (picture pleasantness) (1–9).
†Arousal ratings (1–9).

(Shaygan et al. (2017)

# **Background:** Static Visual Pain Relief

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**Findings:**

- **Positive emotional enforcement, not distraction alone, drove the effect**
  → high-"valence" images were more effective than emotionally neutral stimuli (e.g. optical illusions).

⇒ Images associated with **<u>positive context</u>** provided **better results**

| | Picture | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Loved Ones | | Strangers | | Landscapes | | Optical Illusions | |
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*Valence ratings (picture pleasantness) (1–9).
†Arousal ratings (1–9).

(Shaygan et al. (2017))

# **Background:** Static Visual Pain Relief

**Observed limitations:**

- Effects depend strongly on **personal relevance** (e.g., one's own photos).
- Visuals are passive and provide little adaptation to patient state or posture.
- Limited control over **attention dynamics** during longer or more intense procedures.

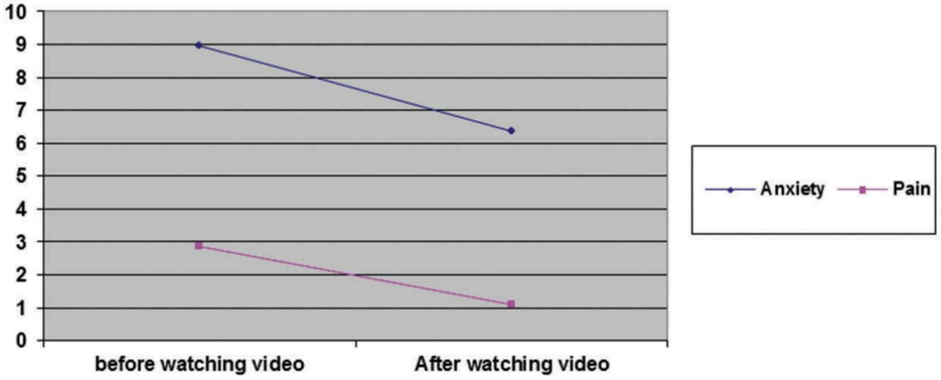
**Implication:**

- Static images demonstrate *that* vision matters —
  but offer limited tools for **sustained or adaptive pain modulation**.

# **Background:** Passive Video and Animated Visual Interventions

**Extending beyond static images:**

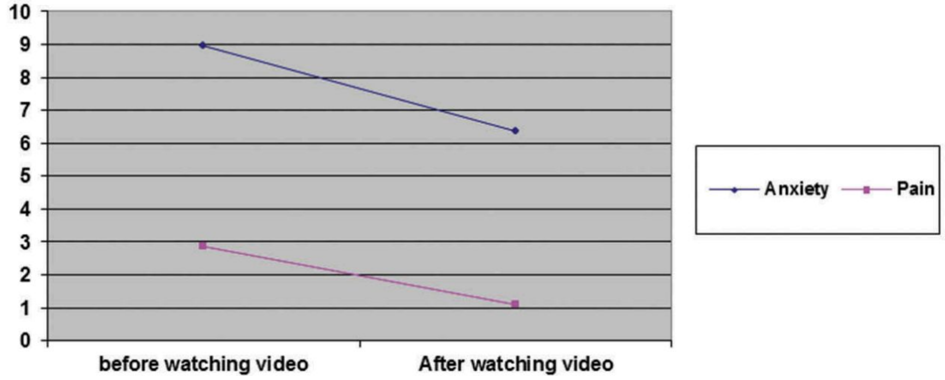
- Some studies use **animated or video-based visual content** during procedures
- Content is **scripted and passive**, often narrative or hypnotic in structure
- No interaction, no embodiment




Arnon et al. (2018)

# **Background:** Passive Video and Animated Visual Interventions

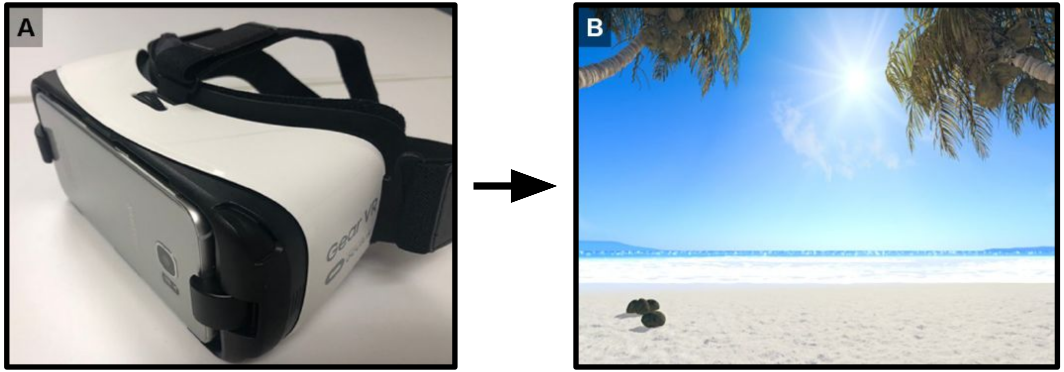
- Designed to maintain attention and induce relaxation through imagery and narration
- Short animated videos reduced **stress and pain ratings** in pediatric surgery settings




Arnon et al. (2018)

# From Passive Stimuli to Active Perceptual Engagement

- Interactive digital interventions extend pain modulation by actively engaging attention and perception (e.g. Peña et al., 2023) beyond visual stimuli
- **Virtual Reality** (VR) proven an effective non-medical method to reduce pain and anxiety during procedures
- Effects driven by immersive audiovisual engagement



# Immersive VR for Procedural Pain

Immersive VR extends visual modulation by introducing immersion, presence, and spatial consistency.

- Head-mounted displays create a **controlled visual environment**
- Immersion **reduces awareness** of the **clinical setting**
- Systems may be **interactive or non-interactive**

# Immersive VR for Procedural Pain

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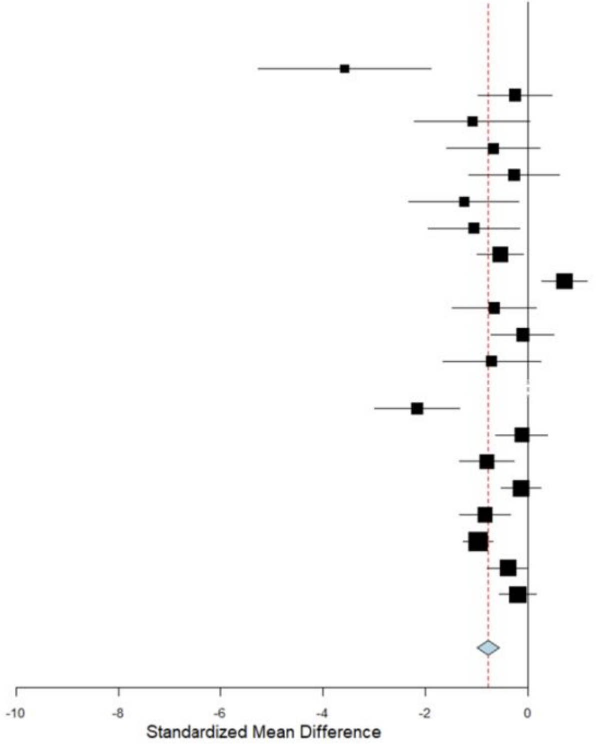
## Case Study:

- Large-scale meta-analysis of Randomized Controlled Trials (RCTs) shows VR significantly reduces pain across medical procedures.
- Effects observed in both adults and pediatric populations.

| Studies | Estimate | (95% C.I.) |
|---|---|---|
| Hoffman(a) 2001 | -3.57 | (-5.26, -1.89) |
| Sander Windt 2002 | -0.25 | (-0.98, 0.47) |
| Das 2005 | -1.09 | (-2.21, 0.04) |
| Wolitzky 2005 | -0.68 | (-1.58, 0.22) |
| Gold 2006 | -0.27 | (-1.15, 0.61) |
| Chan 2007 | -1.25 | (-2.32, -0.18) |
| Hoffman(b) 2008 | -1.06 | (-1.95, -0.16) |
| Carrougher 2009 | -0.54 | (-0.99, -0.09) |
| Konstantinos 2009 | 0.71 | (0.27, 1.14) |
| Maani 2011 | -0.66 | (-1.48, 0.16) |
| Kipping 2012 | -0.10 | (-0.71, 0.51) |
| Jeffs 2014 | -0.71 | (-1.66, 0.25) |
| | . . . | |
| Pathoulas 2022 | -2.16 | (-2.99, -1.34) |
| Perdue 2022 | -0.11 | (-0.63, 0.40) |
| Ryu 2022 | -0.81 | (-1.33, -0.28) |
| Thybo 2022 | -0.14 | (-0.52, 0.25) |
| Wang 2022 | -0.84 | (-1.34, -0.35) |
| Xie 2022 | -0.97 | (-1.26, -0.68) |
| Yildirim 2022 | -0.39 | (-0.79, 0.01) |
| Bosso 2023 | -0.20 | (-0.56, 0.16) |
| **Overall (I^2=93.4 %, P< 0.01)** | **-0.78** | **(-1.00, -0.57)** |




Teh et al. (2024)

# Motivation and Research Gap

**Most VR systems assume:**

- Upright orientation
- Head-Motion Support
- Controller or free-arm input


**Gap:** Prone posture breaks these assumptions

- Standard VR apps induce disorientation and visual discomfort when face-down
- A large number of interventional pain procedures are performed prone
- Minimal head motion → large perceptual instability

**Safety risk**: Existing VR implementations are unstable or disorienting when face-down

# Design Implications: Interaction Under Physical Constraints

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- Conventional VR interaction also applies to **interactive arm/controller input**.
- In prone medical procedures, patients exhibit **minimal head motion**, **restricted limb movement**, and **orientation mismatch** between the physical body and virtual camera.
- These conditions amplify **perceptual instability**, **increase discomfort,** and make controller/gesture-based interaction **unsafe or infeasible** (Palmisano et al., 2023).

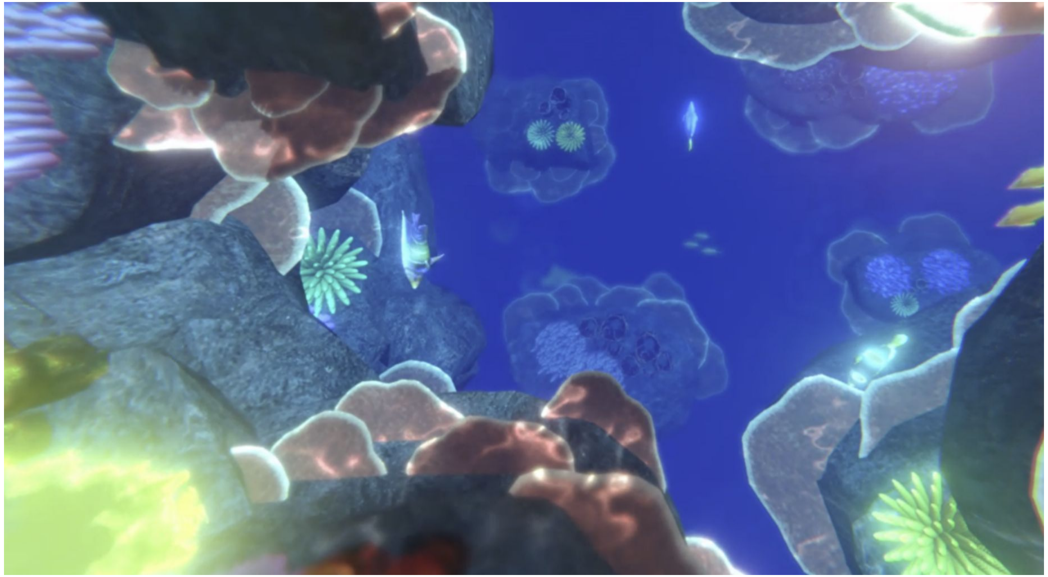
# Project Goals and Approach

**ProneVR**: a constraint-aware VR system for prone procedures

Designed for:

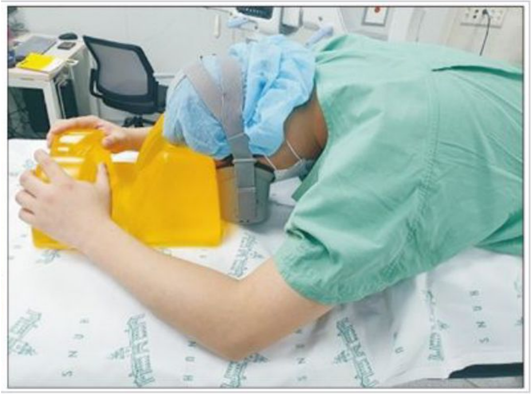
- Immersive visual interaction for perceptual engagement
- Controller-free user interaction
- Horizontal (Prone) application viewing
- Minimal physical movement

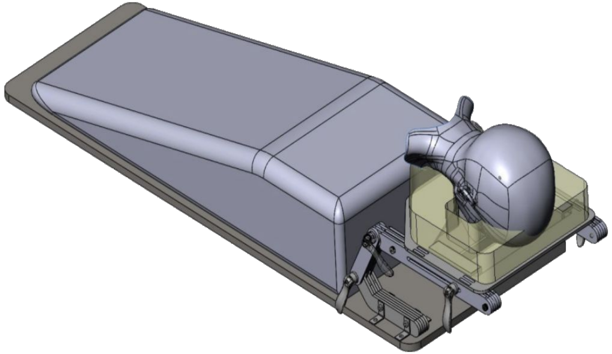
Built for clinical safety and procedural compatibility



# Key Technical Contributions

- VR system explicitly designed for prone viewing
- Graphics-driven immersion designed to dominate visual attention
- Audiovisual co-motion between camera, agents, and sound sources
- Spatial audio integrated as a depth and presence cues
- Latency optimization
- Shader-based visual effects for depth, opacity, and atmospheric perspective

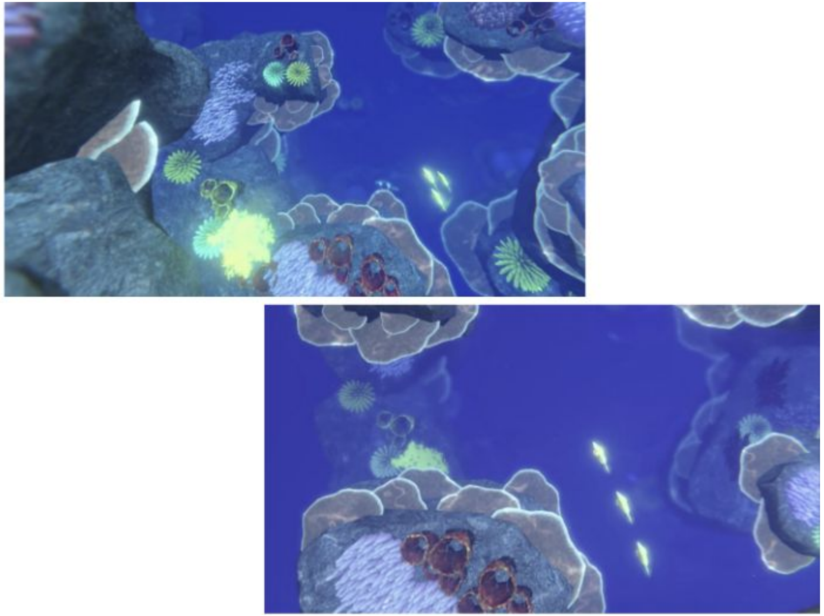




# Our Research Development

- Developed underwater VR scene with stabilized motion and depth cues
- Implemented spline-based organism animation and atmospheric rendering effects
- Integrated perceptual tuning to reduce discomfort during prone viewing

  ⇒ Iteratively refined through user testing at the VIDi lab



Video Demo Link (Martin et al., 2025)

# Clinical Evaluation and Demonstration

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***ProneVR - Design and Evaluation of a Controller-Free Immersive VR for Pain Management***
Michael R. Martin; Garrick Chan; Michael J. Jung; Kwan-Liu Ma
Pain Medicine Department, UC Davis Health, November 24, 2025
https://github.com/MichaelMartinTech/ProneVR-Demo

# Deployment Plan

- Deploy ProneVR in live clinical procedures
- User studies with patients in prone position
- Design and Develop VR comfort metrics through measured physiological sensing
- Assess user comfort under constrained head motion
- Validate system behavior outside controlled lab settings

# Future Directions

1. Explore Interactive Elements in Physically Limited Environments (eye tracking)
2. User-tuned scenes, adjusted based on comfort level
    - Generative scene experimentation with Generative AI (GenAI)
3. Formal evaluation of adaptive input models across diverse prone-constrained postures.
    - Sensors for Psychophysiological state-informed adaptation

# **Direction 1:** Exploring Interactivity in Physically Limited Environments

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**Design implication: interaction must follow perception, not movement**

- Under physical constraints, interaction cannot rely on motor execution.
- Instead, interaction must be derived from **what the user attends to**, rather than **what the user manipulates**.

**Reframing Interaction for ProneVR**

- Interaction not treated as task execution, but as **attention-aware modulation of the visual experience**.
    - Enables lightweight, clinically compatible interaction **without violating safety, sterility, or comfort constraints.**

# **Direction 1:** Exploring Interactivity in Physically Limited Environments

**Eye tracking as an attention-based interaction primitive**

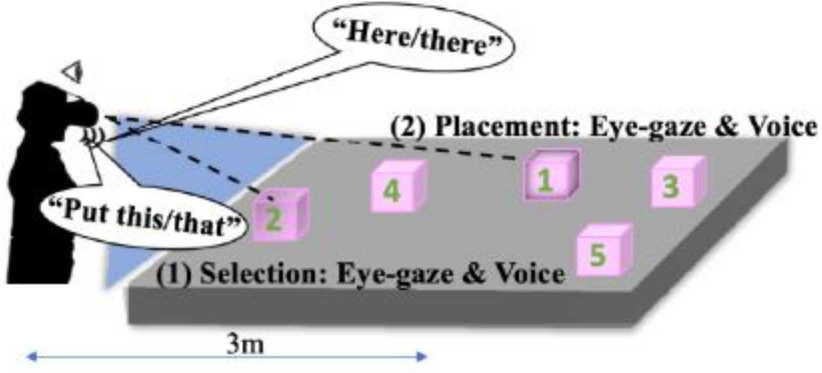
- Provides **hands-free, posture-independent signal** that remains available even under severe physical limitation.
- Gaze-based selection enables effective interaction in VR when traditional inputs are impaired

⇒ Shifts control from motor action to **perceptual intent** (Isomoto et al., 2022; Monteiro et al., 2023).

# **Direction 1:** Attention-Based Interaction

**Case Study:**

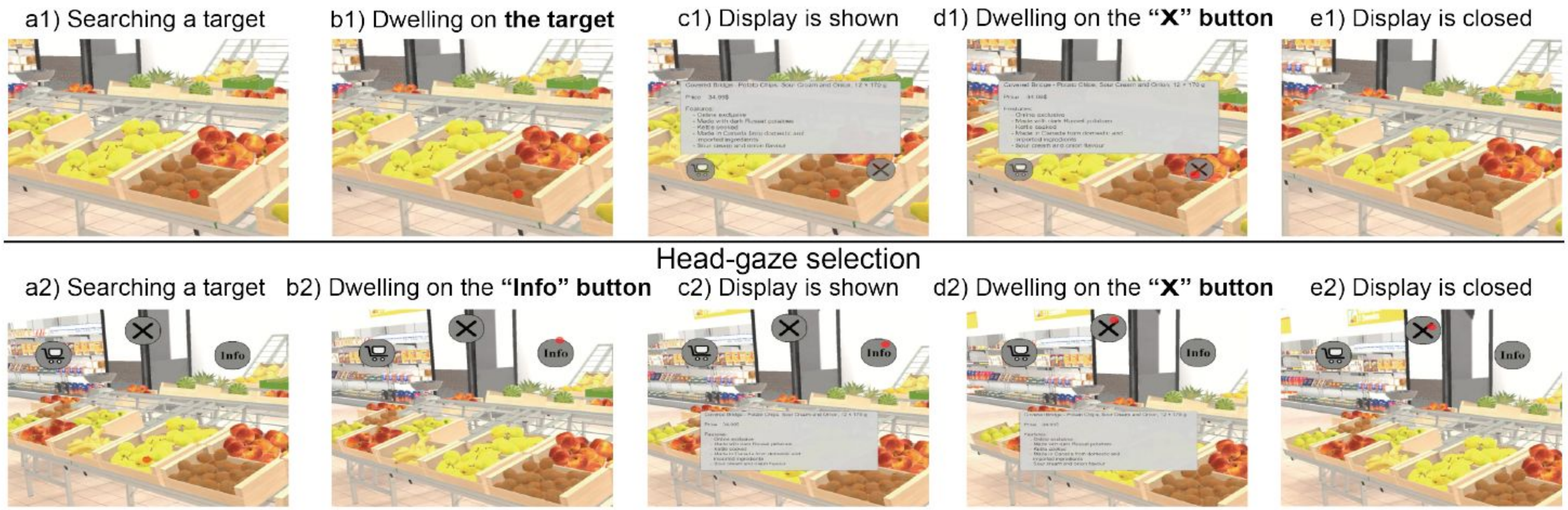
- Gaze-based interactions remains usable under mobility impairment (Ghasemi & Jeong, 2022)
- **Example:** Gaze + Voice Interaction
- Reduces physical workload and fatigue compared to hand-based input




Eye-gaze & Voice

# **Direction 1:** Attention-Based Interaction

- Interaction where attention is directed rather than how actions are performed




Ghasemi & Jeong, (2022)

# **Direction 1:** Attention-Based Interaction

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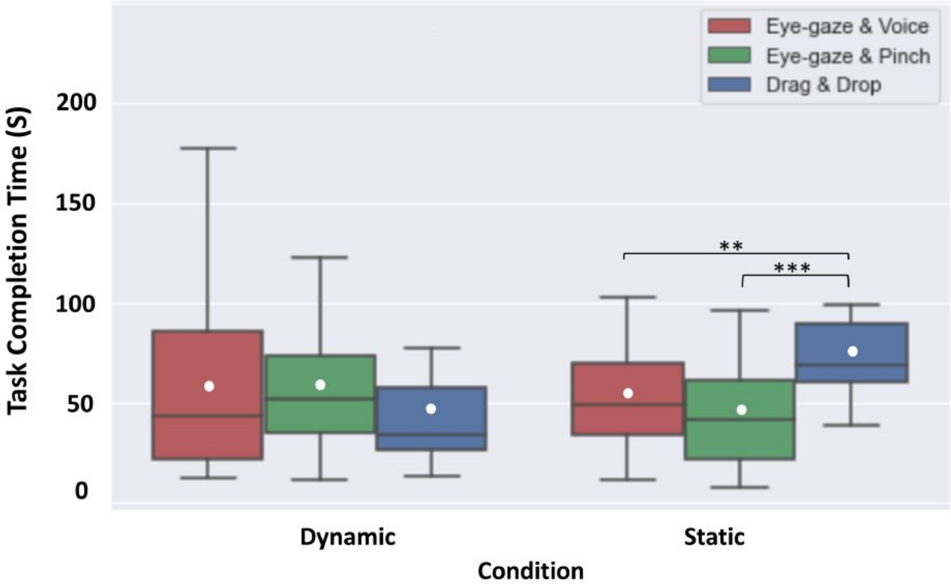
- In non-time-critical and therapeutic contexts, **slower but reliable selection mechanisms** (e.g., dwell-based gaze) are acceptable and often preferred (Mutasim et al., 2021).

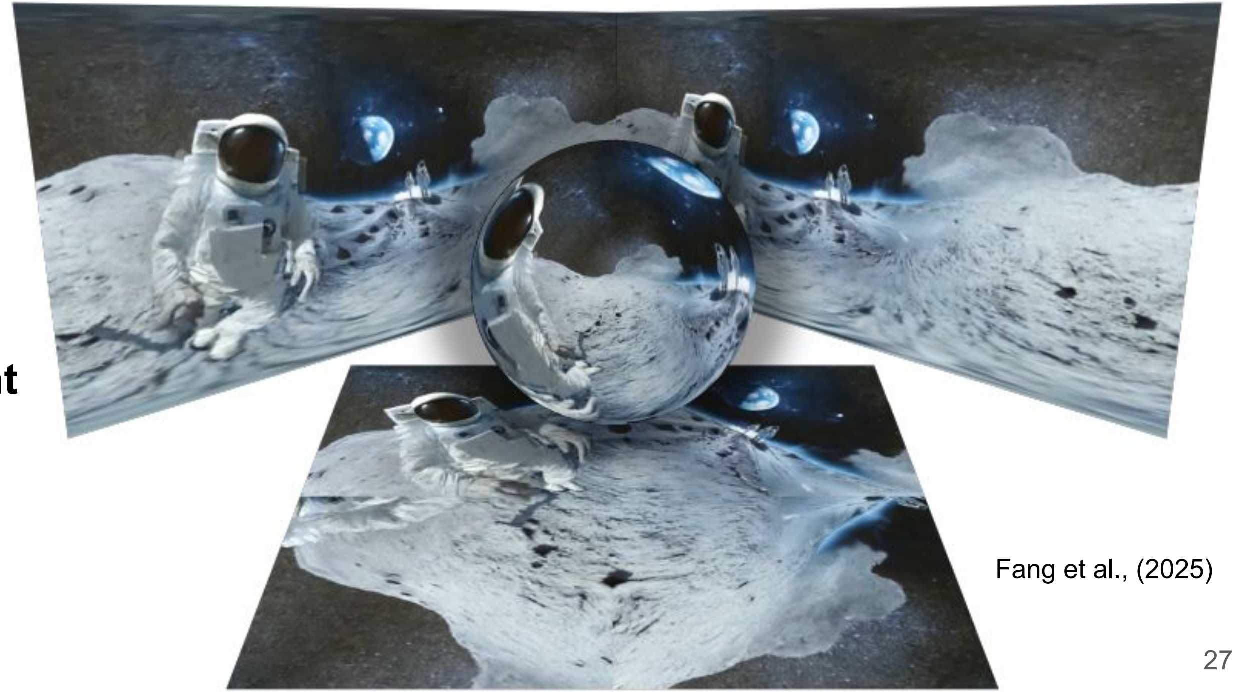



Task completion time for each session Ghasemi & Jeong, (2022)

# Direction 2: Generative AI (GenAI)

- From Curated Scenes to Procedurally Generated 360° Environments (Wang et al., 2025)
- Extending set of  immersive scenes to **on-demand generation of calming 360° environments**.

- Provides:
  - **Personalization**
  - **Content diversity**
  - **Long-term deployment** without manual asset creation



Fang et al., (2025)

# Direction 2: GenAI Panoramic Video

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Naive multi-view stitching fails in VR due to **global inconsistency and wrap-around artifacts**, which are especially disruptive in immersive settings.

Martin (2026)

# Direction 2: GenAI Panoramic Video

**Panorama generation requires explicit architectural changes**, not just prompt engineering:

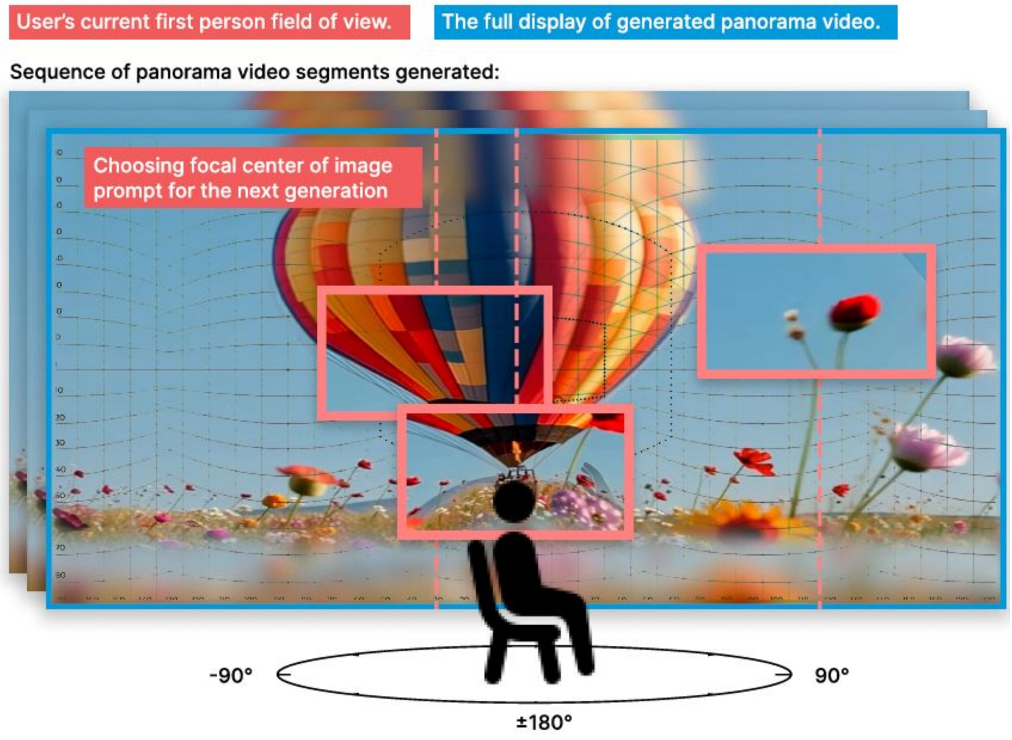
- Dual-branch diffusion separates **global panorama structure** from **local perspective realism**.
- Circular padding and rotation-aware training are required to maintain seam continuity.


Loop Inconsistency (red), Distorted Lines (yellow), Repetitive Objects / Bad Layout (blue)

Zhang et al. (CVPR 2024)

# Direction 2: GenAI Panoramic Video

- Iterative video generation conditioned on prior frames
- Continuous spatial context beyond fixed camera framing
- Adaptive content creation
- Serve as emerging alternative to manually authored VR scenes




The VR Immersive environment setup for video panorama generation, where users can rotate and make creative decisions based on what they see. Wen (2025)

# Direction 2: GenAI Panoramic Video

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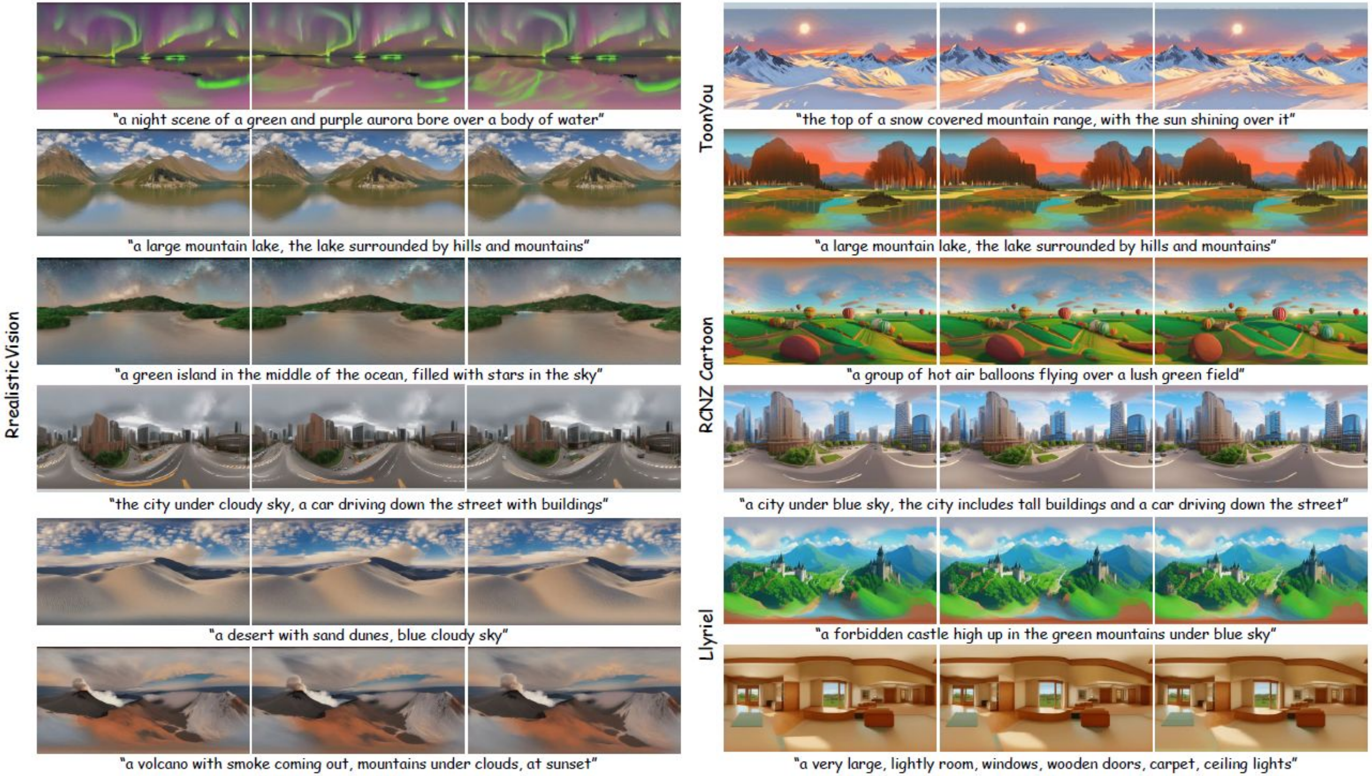
Example: 360DVD

- **WEB360 dataset** align training data w/ panoramic motion distributions.
- Retrofits pretrained video diffusion models without retraining from scratch
  - Lightwieght 360-Adapter

https://akaneqwq.github.io/360DVD/




Wang et al. (2024)

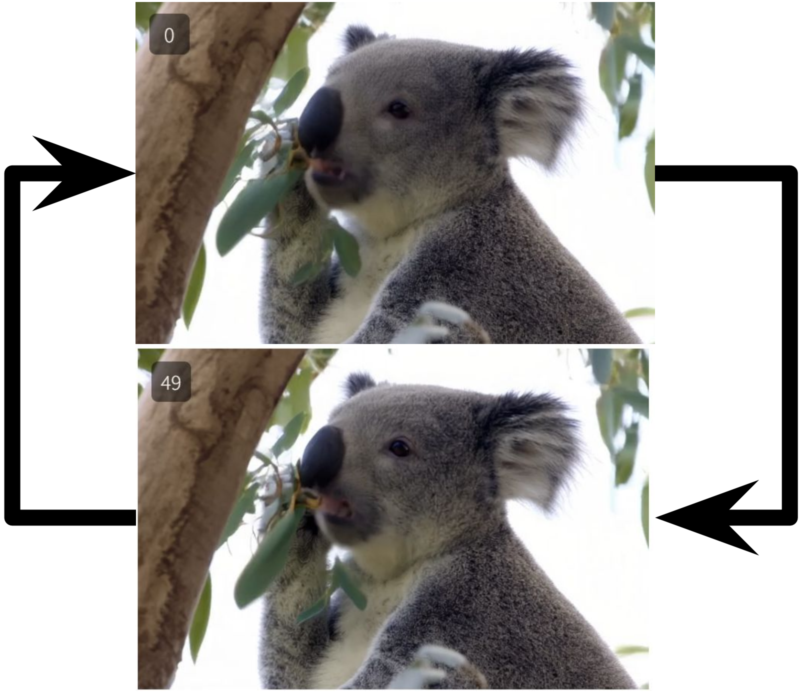
# Direction 2: Seamless GenAI Video



- Video clips with **intrinsically seamless motion**, avoiding perceptual resets that draw attention back to the clinical context.

https://mobius-diffusion.github.io/

**Start Frame**




**End Frame**

Bi et al. (2025)

# Direction 2: Generated 3D Scenes




The Framework for Text-Driven 360-Degree 3D Scene Generation using Text-Driven 360-Degree Panorama Generation. This framework accommodates both Text-Only Generation and Text-Driven NFoV Outpainting methods. The input NFoV image is omitted when employing text-driven NFoV outpainting methods for simplicity. "3D lifting" denotes the transformation from a generated 360-degree panoramic image to a 3D scene representation by inferring the underlying geometry of the scene.

(Wang et al., 2025)

# Direction 2: Generated 3D Scenes

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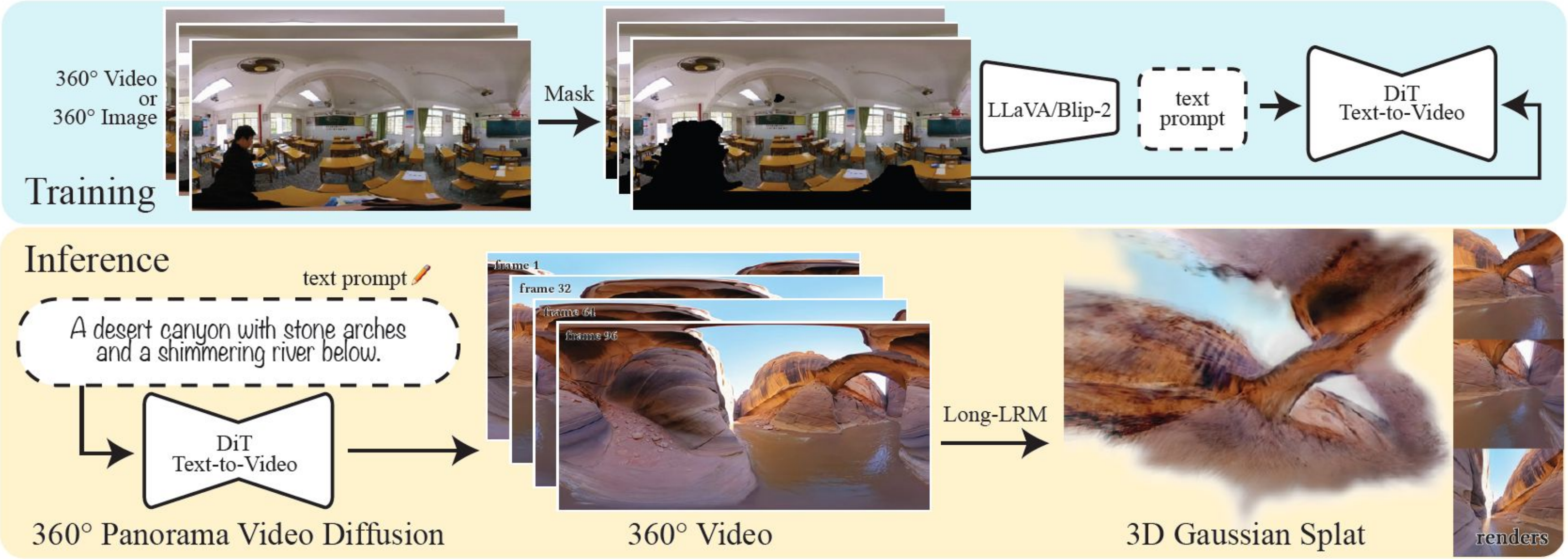


(Zhang et al., 2025)

# Summary

- Designed and implemented an immersive therapeutic VR system
- Integrated real-time rendering with shader-based visual effects
- Developed spatial audio-visual synchronizations
- Built interactive simulation tuned for perceptual stability
- Implemented AI-driven ecosystem with camera-aware behavior
- Validated through clinical demonstration and planned patient studies

We aim to integrate these future Directions: Exploring Interactivity, GenAI, Patient Evaluation

# References

**[1] Ang, S., & Quarles, J.** Reduction of cybersickness in head mounted displays use: A systematic review and taxonomy of current strategies. *Frontiers in Virtual Reality*, 4, Article 1027552, 2023.https://doi.org/10.3389/frvir.2023.1027552

**[2] Arnon, Z., Hanan, H., & Mogilner, J.** The effect of a hypnotic-based animated video on stress and pain reduction in pediatric surgery. *International Journal of Clinical and Experimental Hypnosis*, 66(2), 123–133, 2018.
https://doi.org/10.1080/00207144.2018.1421353

**[3] Bates, R., & Istance, H. O.** Towards eye based virtual environment interaction for users with high-level motor disabilities. International Journal on Disability and Human Development, 4(3), 2005. https://doi.org/10.1515/IJDHD.2005.4.3.217

**[4] Bi, X., Yuan, J., Liu, B., Zhang, Y., Cun, X., Pun, C.-M., & Xiao, B.** Mobius: Text-to-seamless looping video generation via latent shift. *arXiv preprint*, arXiv:2502.20307, 2025.
https://arxiv.org/abs/2502.20307

**[5] Coutray, K., Barbel, W., Groth, Z., & LaViola Jr., J. J.** NeuroGaze: A hybrid EEG and eye-tracking brain–computer interface for hands-free interaction in virtual reality. *Frontiers in Human Neuroscience*, 19, Article 1695446, 2025. https://doi.org/10.3389/fnhum.2025.1695446

**[6] Fang, Z., Zhu, K., Liu, Z., Liu, Y., Zhai, W., Cao, Y., & Zha, Z.-J.** ViewPoint: Panoramic video generation with pretrained diffusion models. *arXiv preprint*, arXiv:2506.23513, 2025.
https://arxiv.org/abs/2506.23513

**[7] Hartfill, J., Hajahmadi, S., Schmidt, S., Marfia, G., & Steinicke, F.** Embracing differences in virtual reality: Inclusive user-centered design of bimanual interaction techniques. *Frontiers in Virtual Reality*, 6, Article 1586875, 2025. https://doi.org/10.3389/frvir.2025.1586875

**[8] Isomoto, T., Yamanaka, S., & Shizuki, B.** Interaction design of dwell selection toward gaze-based AR/VR interaction. *Proceedings of the 2022 Symposium on Eye Tracking Research and Applications (ETRA '22)*, 2022. https://doi.org/10.1145/3517031.3531628

**[9] Kim, J., Kang, J., Choi, J., & Han, B.** FIFO-Diffusion: Generating infinite videos from text without training. *Advances in Neural Information Processing Systems (NeurIPS)*, 2024.
https://arxiv.org/abs/2405.11473, https://jjihwan.github.io/projects/FIFO-Diffusion/

. . .

# References (Continue 1)

**[10] Kirupaharan, P., Ranalli, T.-M., & Venkatasubramanian, K.** Understanding the accessibility of single-user virtual reality environments for adults with intellectual and developmental disabilities. *Proceedings of the 2025 ACM Designing Interactive Systems Conference (DIS '25)*, 2025. https://doi.org/10.1145/3715336.3735782

**[11] Litleskare, S.** The relationship between postural stability and cybersickness: It's complicated – An experimental trial assessing practical implications of cybersickness etiology. *Physiology & Behavior*, Elsevier, 236, Article 113422, 2021. https://doi.org/10.1016/j.physbeh.2021.113422

**[12] Monteiro, P., Coelho, H., Gonçalves, G., Melo, M., & Bessa, M.** Exploring the user experience of hands-free VR interaction methods during a Fitts' task. *Computers & Graphics*, Elsevier, 117, 1–12, 2023. https://doi.org/10.1016/j.cag.2023.10.005

**[13] Mutasim, A. K., Batmaz, A. U., & Stuerzlinger, W.** Pinch, click, or dwell: Comparing different selection techniques for eye-gaze-based pointing in virtual reality. *ETRA '21 Short Papers: ACM Symposium on Eye Tracking Research and Applications*, 2021. https://doi.org/10.1145/3448018.3457998

**[14] Narkar, A. S., Michalak, J. J., Peacock, C. E., & David-John, B.** GazeIntent: Adapting dwell-time selection in VR interaction with real-time intent modeling. *ACM* (preprint), 2024. https://doi.org/10.48550/arXiv.2404.13829

**[15] Ni, J., Zhang, C.-B., Zhang, Q., & Zhang, J.** What Makes for Text to 360-degree Panorama Generation with Stable Diffusion? IEEE/CVF International Conference on Computer Vision (ICCV), 2025.https://arxiv.org/abs/2505.22129, https://openaccess.thecvf.com/content/ICCV2025/papers/Ni_What_Makes_for_Text_to_360-degree_Panorama_Generation_with_Stable_ICCV_2025_paper.pdf

**[16] Palmisano, S., Allison, R. S., Teixeira, J., & Kim, J.** Differences in virtual and physical head orientation predict sickness during active head-mounted display-based virtual reality. *Virtual Reality*, 27, 1293–1313, 2022. https://doi.org/10.1007/s10055-022-00732-5

**[17] Peña, J., Koebner, I., & Weisman, W.** Can virtual art and attachment priming decrease pain and social disconnection among individuals living with chronic pain and loneliness? A randomized controlled trial using a web-based serious game. *JMIR Serious Games* (preprint), 2023. https://doi.org/10.2196/preprints.52294

**[18] Shaygan, M., Böger, A., & Kröner-Herwig, B.** Valence and arousal value of visual stimuli and their role in the mitigation of chronic pain: What is the power of pictures? *The Journal of Pain*, 18(2), 124–131, 2017. https://doi.org/10.1016/j.jpain.2016.10.007

. . .

# References (Continue 2)

VISUALIZATION & INTERFACE DESIGN INNOVATION


**[19] Teh, J. J., Pascoe, D. J., Hafeji, S., Parchure, R., Koczoski, A., Rimmer, M. P., Khan, K. S., & Al Wattar, B. H.** Efficacy of virtual reality for pain relief in medical procedures: A systematic review and meta-analysis. *BMC Medicine*, 22, Article 64, 2024. https://doi.org/10.1186/s12916-024-03266-6

**[20] Vincent, E., Battisto, D., Grimes, L., & McCubbin, J.** The effects of nature images on pain in a simulated hospital patient room. *Health Environments Research & Design Journal*, 3(3), 42–55, 2010. https://doi.org/10.1177/193758671000300306

**[21] Wang, Q., Li, W., Mou, C., Cheng, X., & Zhang, J.** 360DVD: Controllable panorama video generation with 360-degree video diffusion model. *arXiv preprint*, arXiv:2401.06578, 2024. https://arxiv.org/abs/2401.06578, https://akaneqwq.github.io/360DVD/

**[22] Wang, H., Xiang, X., Xia, W., & Xue, J.-H.** A survey on text-driven 360-degree panorama generation. *IEEE Transactions on Visualization and Computer Graphics*, 2025. https://arxiv.org/abs/2502.14799, https://ieeexplore.ieee.org/document/11224934

**[23] Wen, Y.** “See what I imagine, imagine what I see”: Human–AI co-creation system for 360° panoramic video generation in VR. *arXiv preprint*, arXiv:2501.15456, 2025. https://arxiv.org/abs/2501.15456

**[24] Zhang, Z., Hold-Geoffroy, Y., Hašan, M., Chen, Z., Luan, F., Dorsey, J., & Hu, Y.** Generating 360° video is what you need for a 3D scene. *ACM SIGGRAPH Asia 2025 Conference Papers*, Article 84, 2025. https://doi.org/10.1145/3757377.3763876

**[25] Zhang, C., Wu, Q., Cruz Gambardella, C., Huang, X., Phung, D., Ouyang, W., & Cai, J.** Taming Stable Diffusion for text-to-360° panorama image generation. *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)*, 2024. https://doi.org/10.48550/arXiv.2404.07949, https://openaccess.thecvf.com/content/CVPR2024/papers/Zhang_Taming_Stable_Diffusion_for_Text_to_360_Panorama_Image_Generation_CVPR_2024_paper.pdf

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# Thank you!

Project Summary

Personal Website