

Design and Investigation of a Virtual Reality Platform for Body Dysmorphic Disorder Research

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Abstract: This study investigates the feasibility of a virtual reality (VR) platform for cognitive reframing therapy in body dysmorphic disorder (BDD) using the Meta Quest 2. The prototype presents socially ambiguous scenarios to target interpretation bias through real-time cognitive feedback. Core features include avatar customisation, first-person embodiment, a third-person "mirror" system and interactive decision-making tasks. System performance and scalability were assessed through functional validation, performance profiling and scalability experiments. Results demonstrated 97 % functional reliability, low central processing unit (CPU) utilisation, stable thermal performance and approximately 3 hours of battery life. However, graphics processing unit (GPU) utilisation exceeded 85 %, limiting frame rate to 24 frames per second (FPS). This is below the 72 Hz comfort threshold, indicating a GPU-bound system. While current scalability is constrained, the platform shows strong therapeutic potential. With targeted optimisation, particularly in lighting and asset complexity, the system could support clinically scalable VR interventions, enhanced further through biometric integration for adaptive, data-driven therapy.

Key words: Body dysmorphic disorder (BDD), embodiment, interpretation bias, unity, virtual reality (VR)

1. INTRODUCTION

Body dysmorphic disorder (BDD) is a mental health condition characterised by the hyper-fixation of perceived flaws in physical appearance [1]. Traditional therapeutic approaches often struggle to address the perceptual and interpretive biases underlying BDD. Virtual reality (VR), with its immersive and controllable environments, offers a promising medium for targeted cognitive interventions. This paper presents a six-week investigation into the feasibility of a VR-based therapeutic prototype designed to simulate socially ambiguous scenarios and support cognitive reframing for individuals with BDD. While still in prototype stage, it is intended for further development and clinical refinement. Section 1. introduces the background, research gap, proposed solution, aims, and investigative question. Section 2. describes the methodology and key engineering decisions. Section 3. presents the results and analysis, followed by overall evaluation in Section 4. and conclusions in Section 5.

1.1 Research background and related work

BDD is characterised by persistent negative interpretation biases, where individuals misread ambiguous social cues as appearance-based judgments [1]. Cognitive behavioural therapy (CBT) is a validated approach that helps challenge these distortions [2]. VR has recently emerged as a promising tool for assessing and modifying cognitive biases. Summers et al. demonstrated that VR can simulate ambiguous social situations, with BDD patients showing a tendency toward appearance-related interpretations and elevated distress levels [3]. These findings mirror traditional assessment outcomes and support VR as a valid platform for BDD research. VR's therapeutic impact relies on three core principles. First, embodiment and customisation: personalised avatars enhance emotional engagement and task relevance [4]. Second, perspective: third-person avatar views promote

self-awareness and emotional regulation [5]. Third, therapeutic mechanics: interactive reframing and self-compassion techniques encourage healthier thinking, with game-based formats improving motivation and adherence [6, 7].

1.2 Research gap and project motivation

Despite progress in VR-based mental health tools, current approaches to interpretation bias remain limited. Existing systems, such as that of Summers et al., rely on hypothetical scenarios and lack real-time, interactive engagement [3]. Many use static panoramic videos and fixed avatars, restricting personalisation and omitting therapeutic mechanisms. These designs are typically short-term and unsuitable for longitudinal research. Most VR interventions also focus on exposure therapy, placing users in fear-inducing environments to reduce avoidance behaviours [8]. While effective for desensitisation, this does not address the cognitive distortions central to BDD. Few platforms allow users to actively challenge negative thoughts and receive immediate, structured feedback. This is an essential component of cognitive restructuring.

1.3 Proposed solution and investigation aims

To address these limitations, this study presents *Perceptual Pathways*, an interactive VR platform designed for BDD research. The system combines avatar customisation, first-person embodiment, ten socially ambiguous restaurant scenarios, real-time decision-making and cognitive feedback to support reframing of negative thoughts. Built for repeated therapeutic use, it enables safe exposure without overwhelming emotion and promotes healthier body image perceptions. Designed for supervised use by clinical psychologists, it includes a clinician dashboard that tracks interpretation choices, response times, and engagement across sessions, providing a non-intrusive alternative to static questionnaires. Figure 1 illustrates the game flow.

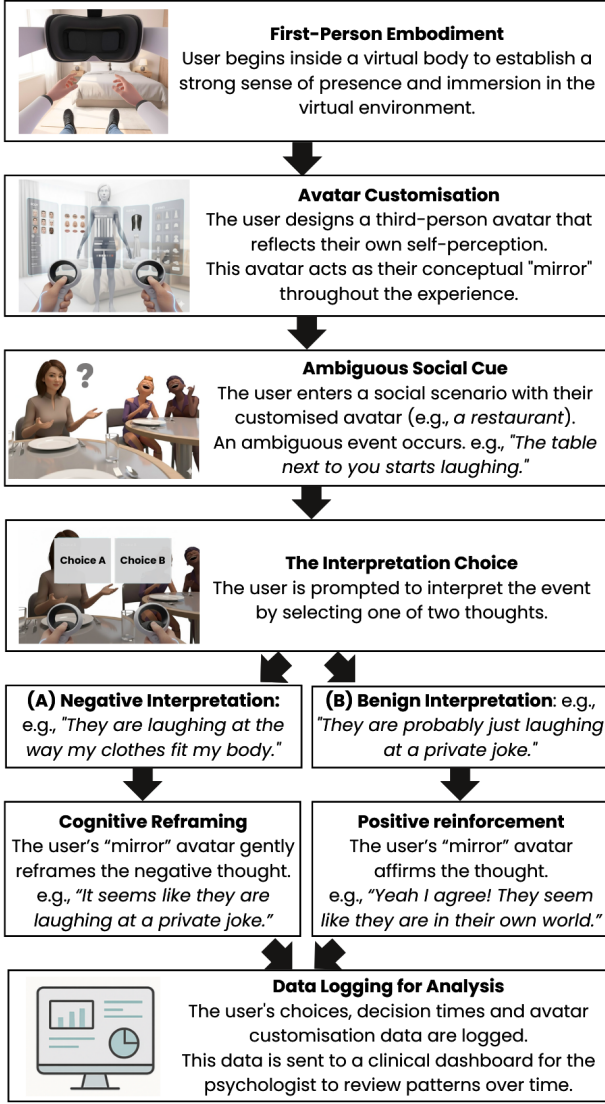


Figure 1: The sequence of events in *Perceptual Pathways* [9].

This investigation focuses on validating the technical feasibility and system architecture of a foundational prototype. While therapeutic efficacy is beyond scope, the system is designed to evolve into a research-ready clinical tool. The guiding research question is: *How can a virtual reality platform be designed and implemented to simulate realistic, perception-based social scenarios in order to support future research and therapeutic applications related to BDD?*

2. INVESTIGATIVE DESIGN AND METHODOLOGY

2.1 High-level system architecture overview

The five-layer architecture of *Perceptual Pathways* separates concerns to support modular development, scalability and testing. This structure was selected over a monolithic design to simplify complexity and enable parallel workflows. Figure 2 illustrates the relationship between the layers.

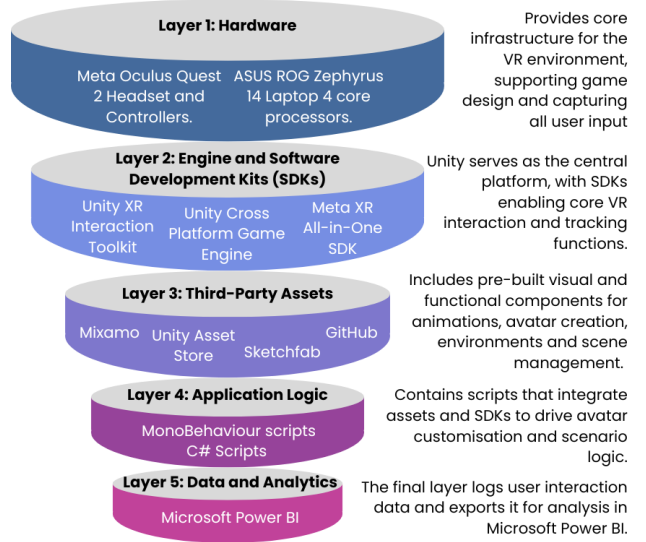


Figure 2: High-level system architecture.

2.2 Investigation strategy, tool justification and technical problem solving

The development was structured as a phased investigation, with each design choice and technical solution contributing evidence toward the central research question. Progressing through four iterative stages, the process evaluated multiple tools against platform constraints, development efficiency and compatibility. Key engineering challenges were identified and resolved through systematic investigation and adaptive problem solving.

2.2.1 Phase 1: development platform and VR hardware. Selecting the core development engine was critical to establishing platform feasibility. After evaluating engine capabilities and deployment pipelines, Unity 6.2 was chosen over Unreal for its strong support for stand-alone VR. Early development was hindered by hardware instability. The Acer Swift 3's limited graphics and memory caused frequent Unity crashes with high-polygon assets. Migration to an Asus ROG Zephyrus 14, equipped with a dedicated NVIDIA graphics processing unit (GPU) and expanded random access memory (RAM), resolved these issues and enabled stable three-dimensional (3D) rendering, highlighting the importance of proper hardware scoping. The Meta Quest 2 was selected as the target headset for its affordability, representative performance and widespread use. A stable development pipeline was established by integrating the Meta extended reality (XR) software development kit (SDK) for tracking and Unity's XR interaction toolkit for standard VR mechanics. This layered architecture allowed focus on novel components. Early build tests revealed driver incompatibility with the headset, which was promptly resolved, validating the deployment path and confirming the viability of the selected toolchain.

2.2.2 Phase 2: user experience and interaction framework. With a stable development environment established, the investigation progressed to designing the user’s interactive journey. This phase focused on constructing intuitive scene transitions, reliable input handling and immersive environmental design.

The start menu and instructional scenes were designed to introduce the therapeutic context calmly, with C# scripts managing scene transitions shown in Figure 3. VR controller inputs were mapped to joystick and trigger functions for locomotion and UI selection. During integration, a conflict between interaction managers caused the right controller to fail, while the left remained functional. The issue was resolved by assigning primary input to the left controller and repurposing the right controller for application exit, ensuring consistent interaction and demonstrating effective debugging.

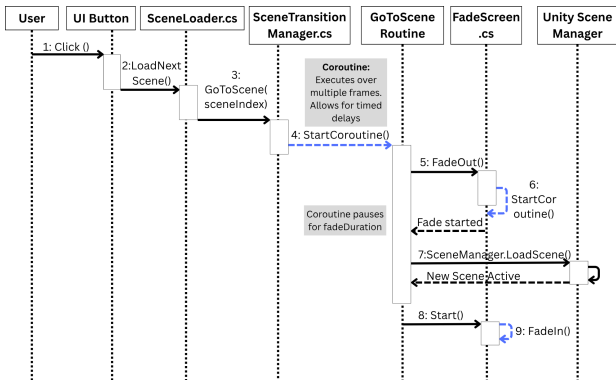


Figure 3: Scene transition system sequence diagram.

To accelerate development, pre-built assets were sourced from the Unity Asset Store, Sketchfab and GitHub. This integration-focused approach enabled rapid prototyping while allowing development effort to concentrate on novel interaction logic. The virtual environments were selected for therapeutic neutrality. These were integrated and rendered with appropriate lighting and physics colliders to create coherent, interactive spaces optimised for VR comfort. A key design pivot occurred during the implementation of the mirror feature. The original plan to include a real-time reflective mirror was abandoned due to incompatibility with Unity’s universal render pipeline (URP). Custom-built solutions failed to achieve realistic reflections, and available third-party assets were incompatible with the current Unity version. In response, the feature was reimagined as a “third-person mirror”, a static camera view that allows users to observe their avatar externally while remaining embodied in first person. This conceptual shift resolved the technical impasse and enhanced therapeutic value by enabling low-cost, performance-efficient self-observation.

2.2.3 Phase 3: first-person embodiment. Creating a convincing sense of embodiment was a key challenge. Closed platforms like Ready Player Me and VRChat were rejected due to limited customisation and data access. Instead, Mixamo’s open-source, pre-rigged humanoid models were adopted, offering a standard skeletal hierarchy that simplified integration and enabled rapid deployment.

To enable full-body tracking within budget, the free Meta movement SDK was used. This 3-point inverse kinematics (IK) system estimates body pose using the head-mounted display (HMD) and two controllers. It was retargeted to a custom Mixamo avatar by mapping tracking anchors to bone transforms as shown in Figure 4. Building a first-person camera rig ensured synchronisation between physical head movement and the virtual viewpoint.

Initial implementation exposed three issues: mesh occlusion from camera placement inside the avatar’s head, head-body de-synchronisation due to incorrect parenting, and jitter from overlapping tracking hierarchies between Unity’s XR origin and the Meta SDK rig. These indicated misalignment between SDK anchors and the avatar’s skeleton. To resolve this, Unity’s XR Origin was replaced with the Meta Movement SDK’s “Building Block” prefab, which includes head, hand and body anchors updated by Quest 2 tracking. The Mixamo avatar was re-parented accordingly. The Unity camera was attached to the HeadAnchor with the head mesh excluded from the culling mask. Anchor offsets were tuned to centre the camera behind the avatar’s eyes. Further data collection and results are detailed in Section 3.

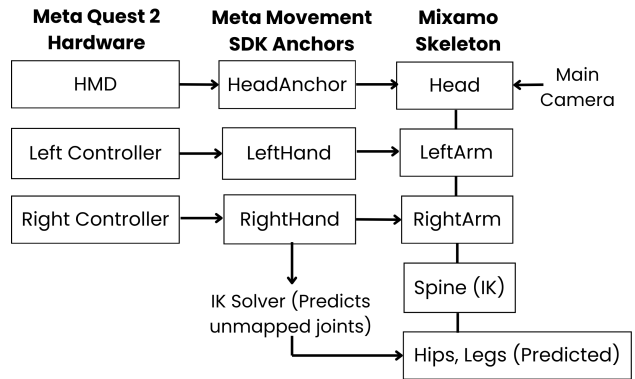


Figure 4: Anchor-to-bone mapping for 3-point IK retargeting using Meta Movement SDK and Mixamo.

2.2.4 Phase 4: data logging and analytics pipeline. To enable behavioural analysis and future research, a lightweight data pipeline was implemented with persistent logging of user interactions. As shown in Figure 5, avatar customisation inputs are captured via UI sliders and recorded into a structured .txt file using a custom C# FileLogger, replacing Unity’s default logging, which failed during deployment.

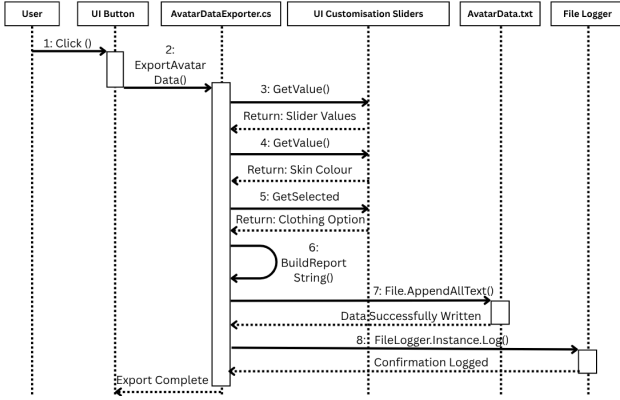


Figure 5: Sequence diagram showing the avatar data export process.

To convert raw logs into analysable datasets, a dynamic Power BI workflow was developed. It parsed text using custom delimiters, un-pivoted entries for normalisation and applied data type conversions. A key behavioural metric (decision time) was derived from the interval between scenario prompt and user response, enabling analysis of hesitation under emotional stress. The resulting dashboard visualises trends such as benign vs negative choices, session-wise changes, customisation value selections, scenario correlations and decision time distributions.

2.2.5 Phase 5: system integration and validation The final phase focused on validating the platform’s reliability and completeness through systematic testing. Functional results, experiments and performance benchmark evaluations are presented in Section 3., demonstrating the system’s operational integrity.

3. EXPERIMENTAL RESULTS AND CRITICAL ANALYSIS

3.1 Functional validation

To assess system reliability, a comprehensive test plan comprising 195 granular cases was executed over one game run. Test cases were grouped into three tiers: Critical (essential for core functionality), Primary (key user-facing features) and Secondary (supporting and aesthetic elements). Each case was evaluated on a binary Pass/Fail basis. Table 1 summarises the results.

Table 1: Summary of functional validation results.

Component	Test Cases	Rate (%)
Critical Systems	90 / 90	100
Primary Systems	79 / 81	98
Secondary Systems	22 / 24	92
Overall Reliability	191 / 195	97

Despite overall reliability, three key issues were identified in technically complex areas. Height adjustments applied during customisation failed to persist

into gameplay, causing object misalignment. This highlights the need for cross-scene parameter transfer. First-person view revealed mesh clipping due to near-plane settings, while third-person mirror mode showed camera jumps and unnatural mouth poses, stemming from collider and camera configuration. These polish-level flaws affect presence but are non-critical. The most significant limitations involved IK: limb clipping, poor ground contact and seated pose inaccuracies reflect constraints of the three-point tracking model.

To assess the three-point IK system, an experiment evaluated its ability to predict full-body posture using only head and hand data. Standardised movements were performed with a consistent avatar and environment, and each action was rated for functional accuracy and subjective believability. The hypothesis anticipated smooth upper-body tracking and acceptable locomotion. As shown in Table 2, the model performed well for arm gestures and directional movement, accurately simulating walking in all directions via head motion. While isolated leg gestures were unsupported, seated poses were reasonably adapted. This level of embodiment meets the platform’s therapeutic requirements.

Table 2: Functional validation of three-point IK model across standardised movements.

Movement category and actions	Status
Hand gestures: wrist rotation	Pass
Arm gestures: elbow bend, dynamic wave	Pass
Locomotion: walk in all directions	Pass
Static poses: seated, idle stance	Pass
Leg gestures: leg lift, knee raise	Fail

3.2 Performance results and critical evaluation

To evaluate technical feasibility, a performance analysis was conducted using Meta’s OVR Metrics Tool during one live gameplay on the Meta Quest 2. Frames per second (FPS) quantifies rendering smoothness. Frame rates below 72 FPS risk motion sickness and breaks immersion [10]. GPU and central processing unit (CPU) utilisation indicate how much processing power is consumed. Sustained usage above 85 % risks thermal throttling and instability. Temperature and battery life ensure safe operation and session viability. The target was under 45 °C and over 1 hour runtime.

A baseline test was conducted on the complete application. The results, shown in Table 3, revealed that CPU usage remained low at 15 %, confirming efficient C# logic. Temperature remained below 43 °C and battery drain was stable, projecting a runtime of nearly 3 hours as per Equation 1. These findings confirm that thermal and power constraints are not limiting factors. In contrast, a critical GPU bottleneck was revealed. Utilisation hovered near 85 %, causing the

frame rate to lock at 24 FPS, below the 72 FPS target. This indicates that the application is GPU-bound in its current form. The diagnosis prompted a further experiment to investigate the impact on scalability.

Table 3: Core performance metrics during a full game-run on the Meta Quest 2.

Metric	Target	Observed	Status
Frame Rate	> 72 FPS	24 FPS	Fail
GPU Utilisation	< 85%	85 %	Marginal
CPU Utilisation	< 80%	15 %	Pass
Temperature	< 45°C	42 °C	Pass
Battery Life	> 1 hour	~ 3 hours	Pass

$$\text{Battery Life (hours)} = \frac{100 \times \Delta \text{time}}{\Delta \text{battery} \% \times 3600} \quad (1)$$

To investigate scalability, a targeted experiment incrementally increased scene count: one, five, fifteen, and twenty-five. The hypothesis predicted linear frame rate degradation, remaining above 30 FPS up to fifteen scenes. As shown in Figures 6 and 7, frame rate plateaued at 24 FPS for one and five scenes then dropped to 10–15 FPS at fifteen. At twenty-five scenes, persistent glitches emerged, forcing the application to terminate midway. GPU utilisation just under 100 % confirms overload. The initial GPU utilisation dip reflects scene loading; the sharp decline indicates non-linear scaling due to unoptimised geometry, real-time lighting and excessive draw calls. Using Equation 2, a single scene demands approximately 255 % GPU capacity to sustain 72 FPS, showing that scalability is currently unachievable with this prototype. However, this is addressable, baked lighting and asset simplification can reduce GPU load and enable multi-scene deployment.

$$\text{Required GPU}\% = \frac{\text{Target FPS}}{\text{Observed FPS}} \times \text{Current GPU}\% \quad (2)$$

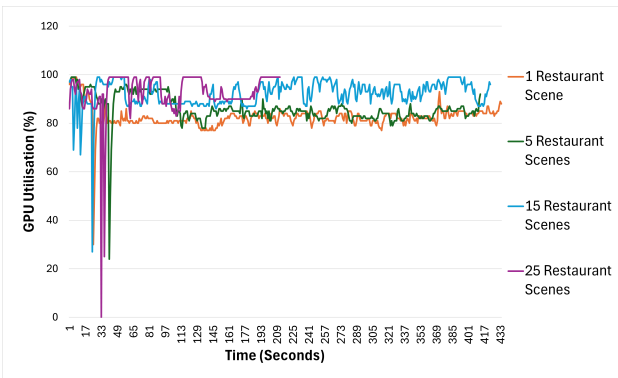


Figure 6: GPU utilisation under incremental load.

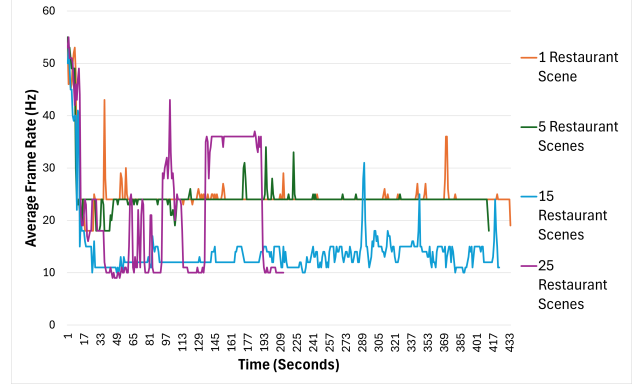


Figure 7: Average frame rate degradation under incremental load.

In summary, the system demonstrates strong CPU efficiency, thermal stability and battery performance, but is critically GPU-bound. Addressing this through targeted optimisation is essential for clinical scalability and sustained user comfort.

4. OVERALL EVALUATION

The investigation aimed to evaluate the feasibility of a VR system for BDD research. This prototype serves as a foundational technical validation. While not yet deployment-ready, its limitations are addressable and do not undermine the viability of VR for therapeutic use. With targeted refinement, the platform can support BDD therapy.

While functional validation confirmed 97% reliability, several limitations must be addressed before clinical deployment. Performance testing revealed a critical GPU bottleneck that compromises frame rate, which induces motion sickness and degrades user experience. This distinction between functional and practical feasibility is the study’s most significant finding. Migrating from real-time to baked lighting is the most effective optimisation to reduce GPU load and improve comfort. The system is also constrained by fixed scenarios, tones and dialogue. Refactoring to a dynamic scripting framework would enable psychologists to customise cues, choices and feedback without developer intervention. Additionally, although the IK model provides believable upper-body tracking, it lacks precision for lower-body gestures. Integrating biometric sensors such as heart rate, skin conductance or eye tracking could enhance therapeutic feedback by visualising stress responses in real time. For clinical use, encrypted, health insurance portability and accountability act (HIPAA)-compliant data storage must replace the current local logger. Future studies should secure ethics approval and include diverse participants. Scenario content and avatar design must reflect varied cultural and gender identities to ensure inclusivity.

Beyond its current scope, the platform shows strong potential for broader therapeutic application and scal-

able deployment. The overall system costs approximately 7500 South African Rands [11]. 50 % less than comparable VR setups [11]. Choosing the Meta Quest 2 was strategic: despite performance constraints, it demonstrates that consumer-grade hardware is nearly sufficient for therapeutic VR. With optimisation, the platform could be deployed in clinics, community centres or remote settings under supervision, improving accessibility. The core interaction loop is also adaptable to other mental health conditions. With minimal changes, it could support interventions for: social anxiety; judgement-based scenarios and depression; feedback interpretation and self-criticism.

In response to the investigative question, this study demonstrates how a VR platform can be designed to simulate realistic, perception-based social scenarios and validated for both, function and performance. It also shows potential to support future research and therapeutic applications in BDD through analytic dashboards that enable cognitive reframing based on interpretation bias. The *Perceptual Pathways* prototype is more than a proof of concept, it is a flexible, accessible foundation for a new class of cognitive behavioural tools. With targeted optimisation and ethical expansion, it holds clear potential for broader impact in digital mental health.

5. CONCLUSION

This investigation confirms the technical feasibility of a VR platform tailored for BDD research, achieving 97 % functional reliability. Performance profiling identified a GPU bottleneck, guiding future optimisation. The system's modular architecture and behavioural logging pipeline establish a scalable foundation for clinical adaptation. With targeted improvements, *Perceptual Pathways* holds strong potential as a flexible tool for digital mental health interventions.

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APPENDIX

Appendix A: Reflection on working as a group

Working in a group for this project provided one of the most valuable learning experiences of the semester. My partner, Rawdah Kurrimboccus, and I worked closely together throughout the six weeks, meeting every day to stay aligned and to support each other through the challenges of building a virtual reality (VR) system from scratch. At the start, neither of us had any experience with VR development or game design, so the first few weeks were dedicated to exploring the Unity cross platform game engine, testing the Meta Quest 2 headset and familiarising ourselves with the fundamentals of VR interaction. We spent long hours experimenting together, sharing discoveries and troubleshooting problems as a team. This collaborative learning phase helped us develop a shared technical language and confidence in the platform before dividing tasks more independently.

Once we were comfortable, we allocated roles based on our interests and emerging strengths. Rawdah focused on scenario engineering, dialogue design and animation, which brought the therapeutic interactions and user choices to life. I focused on embodiment, system integration, performance testing and data analysis. Despite these distinctions, our workflow remained deeply collaborative. Whenever one of us encountered a technical obstacle, the other immediately offered assistance. We often held evening Microsoft Teams calls to finalise major milestones and cross-check each other's progress.

Communication was key to our success. We were transparent about workloads and realistic about deadlines, ensuring tasks and responsibilities were shared fairly. When one of us felt overwhelmed, the other would suggest short breaks or take over smaller tasks to relieve pressure. Rawdah often encouraged me to push through difficult stages and her motivation helped maintain momentum during demanding periods. A memorable challenge occurred when her laptop unexpectedly crashed; rather than pausing the project, she quickly devised an alternative plan and continued working from a backup device, a display of resilience that motivated me to match her commitment.

Our partnership demonstrated the value of mutual respect, adaptability and professional communication. We made decisions collaboratively, balancing creative freedom with project requirements. Although we came from different academic strengths as she also holds a degree in biomedical engineering, our complementary skills allowed us to integrate technical and creative elements effectively. By the end of the project, we had not only produced a functioning VR prototype but also developed a strong sense of teamwork grounded in trust, problem-solving and shared accountability.

This experience reinforced how engineering solutions rarely emerge from individual effort alone. Effective collaboration, learning from each other, communicating openly and supporting teammates through setbacks is essential for tackling complex interdisciplinary problems. Working alongside Rawdah transformed a technically demanding project into an enjoyable and rewarding partnership that strengthened both our technical and interpersonal abilities.

Appendix B: Original, unmarked Project Plan report

The following pages contain the original, unmarked Project Plan report.

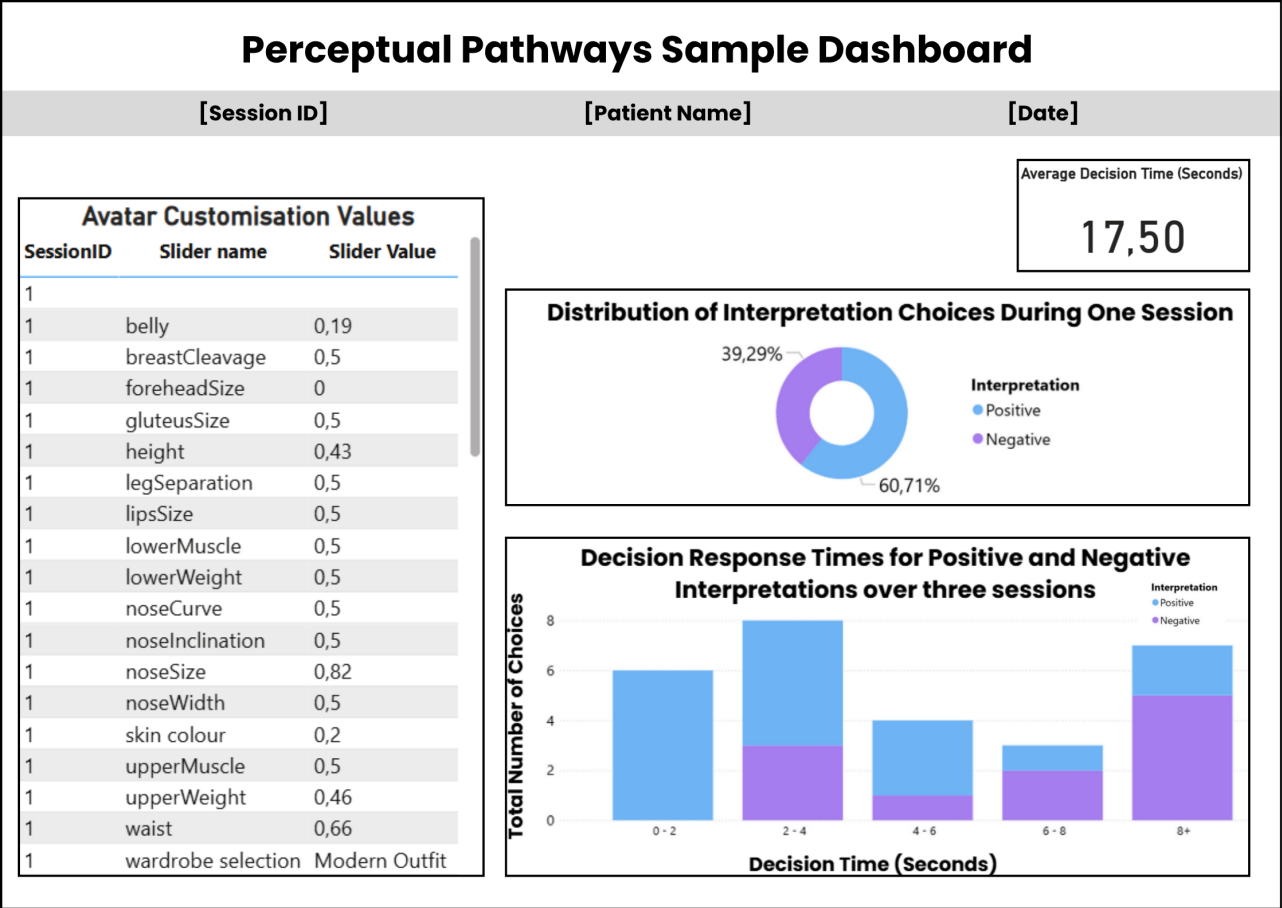


Figure 8: Power BI example dashboard.

Appendix D: GitHub repository link

For access to the final APK build and a walkthrough video recorded directly from the Meta Quest 2 headset, please refer to the project repository:

<https://github.com/Rawdahh/Investigation-Project--A-Virtual-Reality-Mirror-System-for-BDD-Therapy.git>.

Table 4: Mapping of ECSA Graduate Attributes to Report Content

GA Code	Motivation	Report Section
GA 1	The report identifies interpretation bias in body dysmorphic disorder as a complex problem and proposes a novel VR-based reframing system. Evaluation includes synthesis of technical and therapeutic constraints.	Sections 1.2, 1.3, 3.1, 4
GA 2	Specialist knowledge in Unity, inverse kinematics, Mixamo, Power BI, data engineering, data science and behavioural analytics is applied alongside fundamental engineering principles such as system profiling, function tests, performance benchmarking.	Sections 2.1–2.3, 3.2
GA 4a	A structured investigation is conducted through phased development, tool justification and scenario-based testing. The research question is clearly framed and addressed.	Sections 1.3, 2.2, 3.1
GA 4b	Experiments such as frame rate profiling, scalability and IK movement validation are designed with clear objectives and reconciled against predictions. Discrepancies are analysed.	Sections 3.1, 3.2
GA 5	Appropriate tools such Unity, Meta Movement SDK, Power BI are selected and used effectively. Limitations and debugging strategies are discussed.	Sections 2.1–2.4, 3.2
GA 6a	The report is structured professionally with clear language, correct referencing, and effective use of figures and tables. Abbreviations are expanded on first use.	Entire document
GA 8b	Team collaboration is reflected in the mirror redesign, controller debugging, and shared development pipeline. Role division and conflict resolution are discussed in Appendix A.	Appendix A
GA 9	Independent learning is demonstrated through adaptation to hardware constraints, reimagining the mirror system, and implementing a custom analytics pipeline.	Sections 2.1–2.5, 4

Appendix F: Minutes of meetings

The proceeding pages show the minutes of weekly cohort meetings.