FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

A Virtual Dialogue Moderator for Older Adults: A VR-Based Response to Loneliness

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Mestrado em Multimédia

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Abstract

Loneliness is a growing concern among older adults, with well-documented impacts on both physical and mental health. In this context, Virtual Reality (VR) has emerged as a promising tool to foster social interaction among older adults. This dissertation explores the use of a non-immersive VR dialogue moderation system aimed at facilitating structured conversation among adults over the age of 60 and mitigating feelings of loneliness.

A scoping review was conducted to map VR-based interventions focused on improving the social and emotional well-being of older adults, identifying current approaches and research gaps. Based on these findings, an intelligent moderation system was developed that integrates speech synthesis, voice recognition, and conversational memory management, within a 3D Unity-based environment. The system was empirically evaluated with 10 participants, organized into 5 pairs, in three moderated sessions of approximately 30 minutes each. Data collection included the administration of the pre and post-intervention versions of the original and revised UCLA Loneliness Scale, together with qualitative user feedback.

The findings revealed a slight reduction in perceived loneliness. On the original scale, the mean score decreased from 33.1 to 32.9 (Cohen's d = –0.18; p = 0.5911), a difference that was not statistically significant. In contrast, the revised scale showed a reduction from 50.4 to 49.3, achieving statistical significance (p = 0.0067) with a large effect size (Cohen's d = –1.11). Although these results suggest a positive trend, the absolute change in scores was modest, raising questions about its clinical relevance. However, qualitative analysis supported the value of the intervention, highlighting the positive perceptions of naturalness, social presence, and emotional comfort of the participants during the sessions.

The use of a structured moderation system in non-immersive VR may contribute to reducing feelings of loneliness in older adults. Although the findings are preliminary, they point to the potential of this technological approach as a complementary tool for social intervention. More future research with larger samples, longer intervention periods, and improved realism is recommended.

Keywords: Virtual Reality, Loneliness, Older Adults, Dialogue Moderation, Aging Technology

Resumo

A solidão constitui uma preocupação crescente entre adultos mais velhos, com impactos amplamente reconhecidos na saúde física e mental. Neste contexto, a Realidade Virtual (RV) tem emergido como uma ferramenta promissora para promover a interação social entre adultos mais velhos. Esta dissertação explora a utilização de um sistema de moderação de diálogo em RV não imersiva, concebido para facilitar conversas estruturadas entre adultos com mais de 60 anos e atenuar sentimentos de solidão.

Foi conduzida uma *scoping review* centrada em intervenções com RV dirigidas à promoção do bem-estar social e emocional em populações idosas, com o objectivo de mapear abordagens existentes e identificar lacunas na investigação atual. Em resposta, foi desenvolvido um sistema de moderação inteligente, integrando síntese de fala, reconhecimento de voz e gestão de memória conversacional, num ambiente 3D criado em Unity. O sistema foi avaliado com 10 participantes, organizados em 5 pares, ao longo de três sessões moderadas de aproximadamente 30 minutos. A recolha de dados incluiu a aplicação pré e pós-intervenção das versões original e revista da Escala de Solidão da UCLA, bem como feedback qualitativo dos utilizadores.

Os resultados evidenciaram uma ligeira redução na solidão percebida. Na escala original, a pontuação média diminuiu de 33,1 para 32,9 (Cohen's d = –0,18; p = 0,5911), uma diferença que não foi estatisticamente significativa. Em contraste, a escala revista mostrou uma redução de 50,4 para 49,3, alcançando significância estatística (p = 0,0067) com um tamanho de efeito elevado (Cohen's d = –1,11). Embora estes resultados apontem para uma tendência positiva, a alteração absoluta nas pontuações foi modesta, levantando questões sobre a sua relevância clínica. Ainda assim, a análise qualitativa apoiou o valor da intervenção, destacando perceções positivas dos participantes relativamente à naturalidade das interações, à presença social do moderador e ao conforto emocional sentido durante as sessões.

A utilização de um sistema de moderação estruturada em RV não imersiva poderá contribuir para a redução de sentimentos de solidão entre adultos mais velhos. Apesar de preliminares, os resultados indicam o potencial desta abordagem tecnológica como ferramenta complementar de intervenção social. Recomenda-se a realização de estudos futuros com amostras mais alargadas, períodos de intervenção prolongados e melhorias no realismo do sistema.

Palavras-chave: Realidade Virtual, Solidão, Adultos mais velhos, Moderação de Diálogo, Tecnologia do Envelhecimento

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Henrique da Silva Lopes

"Se vi mais longe, foi por estar sobre os ombros de gigantes."

- Isaac Newton

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Abbreviations

INESC TEC	Institute for Systems and Computer Engineering, Technology and Science
AI	Artificial Intelligence
API	Application Programming Interface
VR	Virtual Reality
3D	Three-Dimensional
JSON	JavaScript Object Notation
GPT-4	Generative Pre-trained Transformer 4
VoIP	Voice over Internet Protocol
HMD	Head-Mounted Display
UCLA	University of California, Los Angeles
TCP	Transmission Control Protocol
HTTPS	Hypertext Transfer Protocol Secure
TLS	Transport Layer Security
NLP	Natural Language Processing
XR	Extended Reality
TLS	Transport Layer Security
GDPR	General Data Protection Regulation
RNCCI	Rede Nacional de Cuidados Continuados Integrados
TTS	Text-to-Speech
STT	Speech-to-Text
OS	Operating System
SD	Standard Deviation
GEE	Generalized Estimating Equations
WHOQOL-OLD	World Health Organization Quality of Life – Older Adults version
MR	Mixed Reality
GDS	Geriatric Depression Scale
PANAS	Positive and Negative Affect Schedule
WHO	World Health Organization
CASP	Critical Appraisal Skills Programme
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RCT	Randomized Controlled Trial
M	Mean
IEEE	Institute of Electrical and Electronics Engineers
LTC	Long-Term Care
TV	Television
HTC	High Tech Computer Corporation
KDE	K Desktop Environment
SEM	Standard Error of the Mean
IQR	Interquartile Range
ID	Identification

Chapter 1

Introduction

Loneliness and social isolation are increasingly recognized as critical public health concerns affecting older adults. In Portugal, recent data indicate that 91% of people 65 years of age or older followed in primary care services report experiencing some degree of loneliness, with almost one-third describing it as severe [1]. In addition, the prevalence of loneliness increases substantially with age, affecting 26.8% of people 85 years of age and older [2]. These phenomena go beyond social issues, as they are closely related to a variety of adverse health outcomes, including a higher risk of depression, anxiety, cognitive decline, sleep disturbances, functional impairment, and even premature mortality [3, 4].

Beyond lack of social interaction, loneliness undermines meaning, self-worth, and psychological resilience. Social isolation, often due to reduced mobility, chronic illness, bereavement, or geographic separation, further constrains opportunities for meaningful relationships. Together, these factors can erode emotional and social well-being, which are fundamental components of quality of life in later years.

Well-being in older adulthood is a multidimensional construct that includes emotional, psychological, and social aspects. It includes satisfaction with life, autonomy, a sense of belonging, positive affect, engagement in meaningful activities, and the ability to maintain social roles. According to the WHO, well-being is more than the absence of disease: It represents the presence of positive experiences, functional ability, and personal fulfillment [5]. Promoting well-being in aging populations requires interventions that encourage social connection, emotional regulation, identity continuity, and cognitive vitality.

Traditional strategies for addressing loneliness, such as support groups, community activities, and home visits, often face logistical challenges for older adults. Although Internet and mobile communication tools are now widespread, many older adults still find these tools difficult to engage with and often experience an emotional disconnect in purely digital interactions.

Within this context, Virtual Reality (VR) emerges as a promising alternative. VR technologies allow for the creation of immersive, engaging environments that replicate real-life experiences, enable interaction, and promote opportunities for reminiscence, play, exploration, and co-presence.

Preliminary evidence suggests that VR can raise mood, reduce feelings of isolation, and stimulate cognitive and emotional engagement. In particular, social VR, where users interact with others in shared virtual spaces, shows the potential to strengthen interpersonal bonds and foster a sense of community [6]. However, robust empirical evidence on the long-term effectiveness of VR interventions is still limited and fragmented. Important questions remain regarding which VR content and formats best support positive outcomes, how personal and contextual factors shape user experiences, and how to consistently measure well-being in studies.

Facilitating meaningful interactions in virtual environments remains challenging, especially among older populations. Although immersive technologies provide promising avenues for social engagement, they often lack built-in mechanisms to sustain the flow of natural conversation. In multi-user VR, participants may hesitate, participate unevenly, or struggle with turn-taking, limiting the depth and inclusiveness of the dialogue.

In social VR settings, the absence of structured guidance can result in fragmented conversations or silence, particularly among users unfamiliar with the technology or with each other. This highlights the need for systems that not only enable connection, but also actively support the conversational process. Achieving this requires a delicate balance between facilitation and autonomy: systems must guide without being overly controlling, and encourage participation without rigidly imposing structure.

This project introduces an AI-powered moderator designed to act as a subtle conversational facilitator within immersive VR environments. Its role is to reduce communication barriers, maintain the flow of dialogue, and stimulate engagement when interactions slow down. Rather than relying on rigid, pre-defined scripts, the system adapts dynamically to the conversational rhythm and behavior of participants.

The ultimate goal is to create conditions that make social interaction in VR comfortable, engaging e rewarding for older adults. By embedding intelligent facilitation into the virtual experience, this work addresses a critical and underexplored aspect of social VR: how to cultivate genuine dialogue and connection in artificial environments that lack the natural cues and affordances of face-to-face encounters.

1.1 Context and Motivation

Loneliness in older adults is a complex and multifactorial issue, influenced by factors such as mobility limitations, chronic health conditions, and reduced social opportunities. Beyond its emotional impact, loneliness is associated with serious health risks, including a higher incidence of depression, anxiety, and physical decline. Traditional approaches, such as support groups and psychotherapy, while effective for some, often face obstacles that limit participation, including social stigma and logistical difficulties.

Virtual reality (VR) offers a unique opportunity to create engaging and immersive environments in which older adults can form meaningful social connections. Unlike standard digital communication tools, VR enhances the feeling of presence, making social experiences more vivid and emotionally resonant. However, although VR can promote connections, unstructured virtual environments make it difficult for many older users to initiate or maintain a conversation.

Older adults in particular may hesitate or feel uncomfortable when initiating a dialogue. To overcome this, this dissertation introduces the concept of a structured dialogue moderator. This virtual agent uses natural language processing (NLP) and adaptive conversational strategies to enhance inclusivity, reduce user pressure, and encourage participation in virtual conversations. The goal is to foster smoother and more natural interactions that can positively impact emotional well-being.

1.2 Project

CONNECT LIVES XR is a multifaceted project designed to reduce loneliness and social isolation among older adults through the use of structured and socially enriching Virtual Reality (VR) interventions. In contrast to conventional VR applications that prioritize entertainment or passive observation, this project is grounded in intentional social interaction.

A central component of CONNECT LIVES XR is the integration of an AI-powered dialogue moderator, developed to structure and support interpersonal communication within virtual environments. In addition to enabling one-on-one interactions, the system facilitates group sessions that aim to promote a stronger sense of community and emotional connection.

Using the immersive and interactive capabilities of VR, the project aims to overcome common challenges in communication, such as anxiety, unfamiliarity, or cognitive hesitations, often experienced by older adults. The ultimate goal is to support more confident, comfortable, and meaningful exchanges within virtual environments, improving the overall well-being of the participants.

1.3 Problem Statement

Despite increasing interest in Virtual Reality (VR) as a medium for social interaction, most existing platforms are not adequately designed to support the communicative needs of older adults. These environments often lack the necessary structure for sustained dialogue and tend to overlook specific age-related communication patterns, such as the hesitation to initiate conversations spontaneously. As a consequence, their potential to address loneliness, a pressing and widespread issue among older populations, remains largely untapped. Without supportive design features, VR risks becoming an isolating rather than a connective experience for its intended users.

This research seeks to answer the following question: *Can an AI-powered dialogue moderator, integrated into a VR environment, reduce perceived loneliness among adults 65 years of age and older?*

To address this question, the following research objectives were defined:

- **O1**: Design and implement a VR-based dialogue moderation system adapted to the communicative preferences and needs of adults aged 65 and over.

- **O2**: Evaluate the system's effectiveness in reducing perceived loneliness, based on pre- and post-intervention scores from the original and revised versions of the UCLA Loneliness Scale.

- **O3**: Explore whether the presence of a virtual moderator contributes to more structured and meaningful conversations, based on qualitative feedback and observational data.

- **O4**: Assess participants' overall experience with the system, including perceived emotional comfort, social presence, and usability, through post-session interviews and questionnaires.

1.4 Research Hypotheses

This dissertation hypothesizes that an AI-powered dialogue moderator, embedded within a VR environment, can help reduce perceived loneliness among older adults by enhancing the quality and continuity of their social interactions. The system is expected to facilitate smoother turn-taking, reduce conversational breakdowns, and encourage meaningful participation by offering contextual prompts and personalized guidance. In doing so, it aims to foster a stronger sense of social presence and emotional connection, ultimately mitigating feelings of loneliness through more engaging and structured VR-mediated conversations.

The following hypotheses are proposed:

- **H1**: The use of a VR-based dialogue moderator reduces perceived loneliness among older adults 65 years and older.

- **H2**: The presence of the moderator facilitates deeper connections and more meaningful conversations between participants during virtual interactions.

1.5 Research Questions

This dissertation is guided by the following research questions:

- **RQ1**: Can a VR-based dialogue moderation system reduce perceived loneliness in older adults aged 65 and over?

- **RQ2**: Does the presence of a virtual moderator support deeper and more meaningful conversations in a virtual social setting?

- **RQ3**: How do older adults perceive the usability, effectiveness, and social impact of the system?

1.6 Research Methodology

This study adopts a mixed-methods research design that combines quantitative and qualitative approaches to evaluate the effectiveness of the proposed system. The target population consists of people 65 years or older, selected based on indicators of perceived loneliness.

The data collection process was conducted in three distinct phases. In the pre-session phase, participants completed the UCLA Loneliness Scale to assess their baseline levels of loneliness, alongside a demographic questionnaire used to personalize the interaction. During the session, sessions were conducted in pairs and included three moderated virtual meetings per pair. Observational data were collected, focusing on communication patterns, ease of interaction, and participant behavior. In the post-session phase, participants repeated the UCLA Loneliness Scale and completed a post-session survey that collected qualitative feedback on their experience, perceived impact, and suggestions for improvement.

This structured approach allowed the assessment of both emotional outcomes and usability-related aspects of the system, contributing to a comprehensive understanding of its potential value and limitations. The age threshold of 65 years was adopted according to the World Health Organization (WHO), which defines the beginning of old age at 65 in developed countries, such as Portugal.

1.7 Dissertation Structure

In addition to this introductory chapter, the dissertation is organized into four main chapters, each contributing to a coherent progression from the theoretical foundation to practical implementation and evaluation.

Chapter 2 presents a comprehensive review of the current state of the art in the use of Virtual Reality (VR) to support emotional and social well-being among older adults. This chapter maps existing intervention formats, technological approaches, and outcome measures, identifying critical gaps in the literature, particularly the absence of structured conversational support in social VR environments. It establishes the conceptual rationale and relevance for the development of a virtual dialogue moderator.

Chapter 3 introduces the problem addressed in this dissertation and outlines the proposed solution. Details the conceptual design, system architecture, and implementation of the AI-based moderator developed for non-immersive VR. The chapter describes the technologies used, the structure of the interaction model, the integration of voice and avatar components, and the measures taken to ensure usability and data protection. It also presents a methodological plan for system evaluation.

Chapter 4 reports on the empirical study conducted to assess the impact of the system. It describes the recruitment process, data collection instruments, and analytical methods used to evaluate both quantitative and qualitative outcomes. The chapter presents and interprets the results obtained from pre- and post-intervention assessments of loneliness, as well as participant feedback on system usability, emotional experience, and conversational quality.

Chapter 5 concludes the dissertation by synthesizing the main findings and discussing their implications in the context of social technology for aging populations. Reflects on the limitations of the current study and proposes directions for future research, including system refinement, broader deployment contexts, and long-term longitudinal assessment.

Chapter 2

State of the Art

This chapter introduces the growing interest in Virtual Reality as a promising strategy to support emotional and social well-being in older adults, addressing limitations of traditional interventions for those with mobility or access barriers. VR provides immersive and interactive environments that can help reduce loneliness and social isolation, but there is still a lack of consolidated knowledge about its design, implementation, and evaluation. To address this, the scoping review presented here maps the current empirical evidence on VR-based interventions, highlighting common modalities, objectives, and contextual factors that influence their impact.

A scoping review was selected as the most suitable approach due to the emerging and heterogeneous nature of this field, where diverse VR formats, participant profiles, and outcome measures prevent a systematic review. Scoping reviews are ideal for mapping knowledge, identifying key concepts, and highlighting research gaps in areas lacking cohesive evidence. In this project, the objective was to achieve a broad perspective on how VR-based interventions address loneliness and social engagement in older adults, considering both technological and design aspects.

Focusing solely on conversation moderators, a specific feature of the proposed system, would have severely limited the scope of analysis, as there are very few studies on such tools. By adopting a broader scoping review, it was possible to situate the work within the wider empirical landscape of VR-based social interventions, creating a more robust and meaningful state of the art that can inform future research.

2.1 Methods

This scoping review followed the methodological framework proposed by Arksey and O'Malley [7] and further refined by the Joanna Briggs Institute [8] following a five-stage model comprising: 1) Problem Identification; 2) Literature Search; 3) Data Evaluation; 4) Data Analysis; 5) Presentation of Findings.

The literature search was performed on five electronic databases: Scopus, PubMed, Web of Science, IEEE Xplore, and Google Scholar.

The search strategy combined terms related to virtual reality and older adults with emotional and social well-being outcomes, using the following string: ("virtual reality" OR "VR") AND ("older adults" OR "elderly") AND ("loneliness" OR "social isolation" OR "well-being"). This approach was designed to capture empirical studies researching the use of VR interventions to promote emotional or social well-being in later life.

The primary review question guiding this process was: *What types of virtual reality interventions have been most frequently associated with positive emotional and social outcomes among older adults?*

Relevant records were identified through database searches and citation tracking. All references were exported to reference management software and duplicates were removed. The selection was carried out in two phases: an initial review of the titles and abstracts, followed by a full-text analysis of potentially eligible studies. Data were extracted on study design, sample characteristics, VR systems used, intervention formats, outcome measures, and reported results.

An optional critical appraisal was performed using adapted CASP checklists (Critical Appraisal Skills Programme) to contextualize the methodological quality of the included studies. Although no studies were excluded on this basis, common limitations were observed, including small sample sizes, the absence of control groups, and restricted generalizability of the findings.

2.2 Results

2.2.1 Study selection

The selection process followed the PRISMA guidelines and was conducted in two phases: an initial screening of titles and abstracts, followed by full-text analysis based on predefined eligibility criteria.

Studies were included if they met all the following conditions: (i) the population consisted of older adults (60 years or older), (ii) virtual reality (VR) was used as a central component of the intervention, and (iii) the study reported results related to emotional or social well-being. Only original empirical studies were considered; reviews, opinion papers, and theoretical discussions were excluded. Both immersive and semi-immersive VR modalities were deemed eligible.

Studies were excluded if they did not meet any of these three core criteria, namely, if they did not focus on older adults, did not use VR as a central intervention component, or did not assess emotional or social well-being outcomes. In addition, studies were excluded if the full text was not available or if the article was not published in English.

During the full-text screening phase, several records were excluded on these grounds, most commonly due to insufficient outcome relevance, VR being used only as a supplementary tool, or lack of full-text access.

To ensure methodological transparency, all included studies were evaluated using adapted versions of the Critical Appraisal Skills Programme (CASP) checklists for qualitative and quantitative designs. However, no studies were excluded based on the results of this assessment.

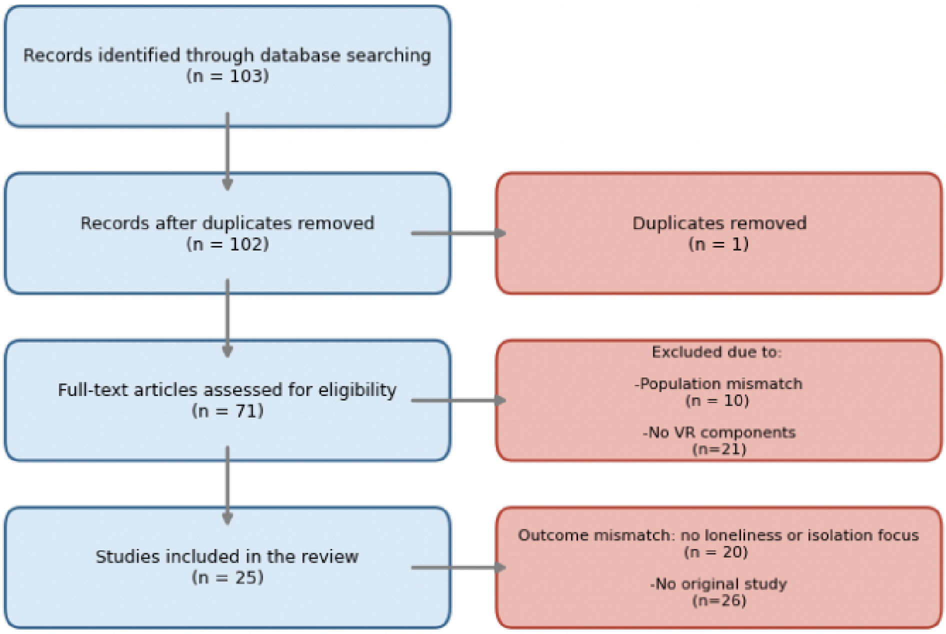

Figure 2.1: Flow Diagram of Study Selection Process.

A total of 25 studies met the inclusion criteria and were retained for descriptive mapping and thematic synthesis. The selection process is detailed in Figure 2.1.

2.2.2 Study characteristics

This section presents an overview of the key characteristics of the studies included in the review. As summarized in Table 2.1, the included studies vary in terms of population, type of intervention, duration, and measured results, offering a comprehensive perspective on how VR has been applied to address loneliness and promote emotional and social well-being among older adults.

Title	**Authors**	**Year**	**Population (Age, n)**	**Intervention**	**Type**	**Duration and Frequency**	**Results**
Using Immersive Virtual Reality to Enhance Social Interaction Among Older Adults: A Cross-Site Investigation	Kalantari et al.	2023	36 older adults (60+)	Social VR with partner-matching across locations	Immersive social VR, multiplayer	Sessions of 2–20 minutes	High engagement ($M = 4.18$, $SD = 0.91$); 83% willing to reuse

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Title	Authors	Year	Population (Age, n)	Intervention	Type	Duration and Frequency	Results
Impact of Virtual Reality (VR) Experience on Older Adults' Well-Being	Lin et al.	2018	52 participants (68+), assisted living	VR vs. TV for travel (relaxation content)	Experimental design with control group, multiplayer	2 weeks, 20-minute sessions	Lower loneliness and depression; satisfaction score $M = 6.13/10$
Metaverse Virtual Social Center for Elderly Communication in Time of Social Distancing	Liang et al.	2023	60 older adults (60–80)	Prototype social VR center using metaverse tech	Multiplayer social VR prototype	4 weeks	Improved mental state based on qualitative feedback; positive engagement and usability
VR in Nursing Facilities: A Randomized Controlled Multicenter Pilot Study	Gruber et al.	2022	17 older adults (62–94)	360º video viewing in VR	RCT pilot, single-player	2 sessions over 2 days	Happiness increased by $+1.00$ ($SD = 1.62$); better effect with animals/people scenes
Exploring the Design of Social VR Experiences with Older Adults	Baker et al.	2019	22 older adults (70–81)	Participatory design workshops on social VR	Qualitative co-design study, multiplayer	Multiple sessions across 2 months	Participants saw VR as helpful for socialization and reminiscence; valued social avatars

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Title	Authors	Year	Population (Age, n)	Intervention	Type	Duration and Frequency	Results
Playing in Virtual Nature: Improving Mood of Elderly People Using VR Technology	Graf, Liszio & Masuch	2020	14 older adults (66–84)	VR forest walk with virtual dog and mini-games	VR nature experience, single-player	1 session of 30 minutes	PANAS positive affect increased from 35.1 to 38.3
Evaluating the Use of Interactive Virtual Reality Technology with Older Adults Living in Residential Aged Care	Baker et al.	2020	5 aged care residents (74–88)	Interactive VR exploration	Qualitative usability study, single-player	Sessions across 2 weeks (1 hour each)	Promoted engagement and reminiscence; noted accessibility challenges with HMDs
Eating Together While Being Apart: A Pilot Study on the Effects of Mixed-Reality Conversations and Virtual Environments on Older Eaters' Solitary Meal Experience and Food Intake	Korsgaard et al.	2020	30 older adults (Mean age = 71.2)	Mixed-reality meals with virtual avatars	Pilot MR study, multiplayer	21 days, 30-minute sessions	Mood significantly higher in MR condition ($p < 0.05$); no significant change in food intake

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Title	**Authors**	**Year**	**Population (Age, n)**	**Intervention**	**Type**	**Duration and Frequency**	**Results**
Interrogating Social Virtual Reality as a Communication Medium for Older Adults	Baker et al.	2019	25 older adults (70–81)	Use of avatars in Social VR (AltspaceVR)	Workshop-based design evaluation, multiplayer	Single 90-minute session	Participants found social VR engaging and enjoyable; expressed interest in avatar customization and communication features
Avatar-Mediated Communication in Social VR: An In-depth Exploration of Older Adult Interaction in an Emerging Communication Platform	Baker et al.	2021	16 older adults (70–81)	Avatar-based interaction in Social VR over 5 months	Longitudinal qualitative study, multiplayer	Sessions of 27–56 minutes across 5 months	Participants found it easier to engage in conversations; positive emotional response and enhanced expressiveness reported
Virtual reality and well-being in older adults: Results from a pilot implementation of virtual reality in long-term care	Chaze et al.	2022	32 older adults in LTC	VR experiences of Canadian locations	Pilot implementation, single-player	Multiple sessions over 2 weeks (n = 102 experiences)	Participants found VR relaxing, engaging, and socially stimulating; enhanced emotional, cognitive, and social well-being

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Title	Authors	Year	Population (Age, n)	Intervention	Type	Duration and Frequency	Results
Being There: Exploring Virtual Symphonic Experience as a Salutogenic Design Intervention for Older Adults	Faw, Buley & Malinin	2021	16 older adults (76–90), incl. 3 with dementia	VR symphonic experience vs. campus tour	Co-design user study, single-player	Single session (timing not stated)	Positive responses to being virtually onstage; enhanced immersion, social connection; no adverse effects
Connecting the Elderly Using VR: A Novel Art-Driven Methodology	Kosti et al.	2024	10 older adults (60–85)	Art-driven social VR (virtual village)	Design pilot, multiplayer	Sessions of 8–10 minutes	Participants appreciated cultural design and experienced increased social engagement and creativity
Older Adults With Cognitive and/or Physical Impairments Can Benefit From Immersive Virtual Reality Experiences: A Feasibility Study	Appel et al.	2020	66 older adults (mean = 80.5)	360º VR nature scenes	Feasibility study, single-player	3 to 20 minutes (single session)	76% completed full session; reported relaxation, engagement, and no side effects; 76% willing to repeat VR

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Title	Authors	Year	Population (Age, n)	Intervention	Type	Duration and Frequency	Results
School's Back: Scaffolding Reminiscence in Social Virtual Reality with Older Adults	Baker et al.	2020	16 older adults (70–81)	Reminiscence in custom social VR ('School Days')	Participatory co-design, multiplayer	27–56 minutes/session over 5 months	Improved social connection and reflection; scaffolded features supported deep reminiscence
Impact of Virtual Reality–Based Group Activities on Activity Level and Well-Being Among Older Adults in Nursing Homes	Li et al.	2024	84 older adults (60–97)	Group VR activities in virtual cottage	Longitudinal, multiplayer	1 session/week for 4 weeks	Flexibility ($\eta^2 = 0.109$), group integration ($\eta^2 = 0.141$), proactivity ($\eta^2 = 0.104$)
Designing Virtual Reality (VR) Experience for Older Adults and Determine Its Impact on Their Overall Well-Being	Lin, Xueyang (Charles)	2017	63 older adults (67–97)	Rendever VR vs. TV	Controlled study, single-player	20 minutes sessions over 2 weeks	VR group showed significantly greater improvement in emotional well-being vs. TV
Older adults' experiences of social isolation and loneliness: Can virtual touring increase social connectedness? A pilot study	Oppert, O'Keeffe & Duong	2023	10 older adults (65+)	360º immersive virtual tours	Qualitative pilot, single-player VR	One session (30 minutes)	Reported comfort, emotional value, engagement; potential for social connection

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Title	Authors	Year	Population (Age, n)	Intervention	Type	Duration and Frequency	Results
Application of virtual reality to enhance therapeutic Tai Chi for depression in elderly people	Qiu et al.	2024	300 older adults (60–66 years)	VR-assisted Tai Chi (Oculus Quest 2)	RCT, VR-based physical intervention, single-player	6 months, 1 session per week	Significant reduction in depressive symptoms in VR group
Breaking Social Isolation With Technology: A Mixed-Methods Study on Virtual Reality for Older Adults Living Alone	Dinet et al.	2024	65 older adults (63–93 years)	Immersive VR (guided walks, relaxation)	Mixed-methods, immersive VR, single-player	2 sessions of 30 minutes	Decreased perceived loneliness, improved well-being; positive participant feedback
RemoteChess: Enhancing Older Adults' Social Connectedness via Designing a Virtual Reality Chinese Chess (Xiangqi) Community	Wei et al.	2025	18 older Chinese adults	Multiplayer VR Chinese Chess with interaction	Pilot design study, multiplayer VR	Several sessions of 8–10 minutes	Increased social connectedness via culturally meaningful interaction

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Title	Authors	Year	Population (Age, n)	Intervention	Type	Duration and Frequency	Results
Designing Virtual Environments for Social Engagement in Older Adults: A Qualitative Multi-site Study	Xu et al.	2022	$\geq$60 years, n = 36	Social VR environment with realistic avatars for paired interaction	Qualitative study, multi-player VR	One session lasting approximately 30-60 minutes	Participants reported enhanced social presence and engagement. Interpersonal compatibility influenced the experience.
The effects of a combination of 3D virtual reality and hands-on horticultural activities on mastery, achievement motives, self-esteem, isolation and depression: a quasi-experimental study	Fan et al.	2022	$\geq$65 years, n = 62	3D VR gardening combined with hands-on horticultural tasks	Quasi-experimental study, single-player VR	8 weeks, 1 session per week, each session lasting approximately 60 minutes	Significant increase in self-esteem ($\beta = 2.18$, $p = 0.005$) and mastery ($\beta = 1.23$, $p = 0.039$) in the intervention group. GEE analysis used.

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Title	Authors	Year	Population (Age, n)	Intervention	Type	Duration and Frequency	Results
Effects of semi-immersive virtual reality exercise on the quality of life of community-dwelling older adults: Three-month follow-up of a randomized controlled trial	Wang	2024	≥65 years, n = 98	Group-based physical exercise using semi-immersive VR (Uniigym)	Randomized controlled trial (RCT), multi-player VR	12 weeks, 2 sessions per week, each session lasting 75–90 minutes	Significant post-intervention improvements in quality of life domains: social participation, autonomy, sensory abilities ($p < 0.05$). Effects not maintained at 3-month follow-up.
Effect of Virtual Reality Sessions on the Mental Health of Institutionalized Older Adults	Restout et al.	2025	42 participants (mean age ≈ 85), institutionalized older adults	Immersive VR relaxation content (360 nature videos)	Quasi-experimental, pre-post, single group	8 sessions over 4 weeks, 10–15 min each	Significant reduction in anxiety ($p < .001$) and depression ($p = .015$); high satisfaction ($M = 8.7/10$)

Table 2.1: Included studies

2.2.3 Types of VR interventions

The included studies in this review present a diverse and nuanced range of VR applications, reflecting a wide landscape of intervention formats tailored to older adult populations. To facilitate a structured understanding, the VR modalities adopted across these studies are organized into thematic categories: social and multiplayer VR, co-designed and participatory VR, passive immersive VR, interactive and cognitive VR, physical-exercise VR, and hybrid or artistic formats. Each category is discussed in depth, with an emphasis on structure, duration, participant interaction format, and therapeutic goals.

A major focus of multiple studies was the use of VR as a social platform to foster interpersonal interaction and emotional connection. Kalantari et al.[9] implemented a cross-site multiplayer intervention in which older adults participated in shared VR experiences at different geographic locations. Short and frequent sessions supported verbal and non-verbal communication in immersive environments, improving perceived social presence. Similarly, Liang et al.[10] introduced a virtual social center designed within a metaverse context, enabling participants to interact in shared virtual spaces that mimicked communal activities. Wei et al.[11] developed a culturally anchored multiplayer experience through a virtual Chinese chess community, improving social connectivity through familiar cultural practices.

Xu et al.[12] contributed a detailed qualitative exploration of one-on-one social VR, where older adults interacted using realistic avatars. The study emphasized the impact of interpersonal compatibility and the potential of avatar-based communication to build rapport. Li et al.[13] also applied group-based VR in a rustic virtual cottage setting to promote integration, initiative, and shared activity among institutionalized older adults. Baker et al.[14] explored the use of commercial social VR platforms in a controlled session, reporting positive feedback on avatar expressiveness and communication capabilities.

The participatory development of virtual reality environments was the hallmark of several studies led by Baker and collaborators. Baker et al.[15] conducted co-design workshops exploring how older adults imagine social VR. The results informed future interventions by incorporating user preferences into system design. In another study, Baker et al.[16] developed a VR school environment based on reminiscence, tailored with participation of the participants to trigger shared memories and social bonds. The sessions lasted five months and allowed deep emotional reflection. Baker et al.[17] further conducted a longitudinal study exploring avatar-mediated interaction over multiple months, noting increased comfort, natural communication, and avatar personalization.

Baker et al.[18] also implemented interactive VR sessions for institutionalized older adults, emphasizing user agency and environmental exploration. Although these were single-user sessions, the focus was on understanding barriers to adoption and identifying strategies to support engagement. Kosti et al.[19] followed a similar participatory model by co-creating a culturally inspired virtual village for art-based engagement, promoting memory recall and creativity through aesthetic immersion and social interaction.

A significant number of studies used passive VR modalities, mainly focused on immersive 360 video. Gruber et al.[20] conducted a two-day intervention in nursing homes, presenting various 360° scenes, such as nature and people, to evaluate changes in happiness and mood. Appel et al.[21] used short single-session VR exposures featuring nature scenes, measuring engagement and relaxation in a large sample of frail older adults. Chaze et al.[22] allowed repeated viewing of Canadian landmarks during multiple sessions, showing increased cognitive and emotional stimulation.

Restout et al.[23] administered eight immersive VR video sessions based on nature over four weeks to institutionalized participants. The study demonstrated significant reductions in clinical symptoms of anxiety and depression. Oppert et al.[24] provided a single immersive tourism session and captured the comfort and emotional value reported by the participants. These studies most commonly used single-player exposure formats that focused on relaxation or affective outcomes.

Other studies explored interactive VR formats with a focus on cognitive stimulation and participation. Graf et al.[25] introduced a forest walk experience that incorporated elements of light interaction and virtual mood enhancing features. Lin et al.[26] compared a virtual travel scenario with television-based relaxation, reporting superior results in reducing loneliness and depressive states. Lin[27] assessed weekly VR sessions for two weeks, showing enhanced emotional well-being compared to a control group.

Fan et al.[28] combined virtual gardening with real-life horticulture, measuring gains in self-esteem, mastery, and achievement motivation. This quasi-experimental study linked immersive interaction with offline activities. These approaches emphasized engagement beyond passive observation and aimed to stimulate psychological activation, memory, and affect regulation.

VR was also used as a vehicle for physical activity with therapeutic objectives. Qiu et al.[29] conducted a 6-month RCT using VR-assisted Tai Chi exercises for depression treatment. Participants performed guided movements in single-user settings, with clinically significant reductions in symptoms. Wang[30] developed a semi-immersive group exercise intervention using weekly sessions over 12 weeks. Improvements in quality of life indicators such as autonomy, sensory function, and social participation, though effects diminished at follow-up.

Korsgaard et al.[31] examined virtual meals in a mixed reality setting, allowing participants to simulate social dining. Although food intake did not change, mood improved during shared virtual meals. These studies highlight the versatility of VR in delivering embodied and social therapeutic content.

Some studies explored hybrid or artistic uses of VR. Faw et al.[32] exposed participants to a VR symphonic concert experience, assessing immersion and aesthetic engagement. Participants reported emotional and social connection, particularly when placed virtually onstage. Dinet et al.[33] administered guided relaxation and walk-based VR interventions, structured to simulate calming environments and assess effects on loneliness. Participants experienced measurable improvements in well-being and decreased isolation.

These hybrid interventions underscore the potential of virtual reality to bridge sensory, cognitive, and social dimensions through creative modalities that transcend conventional therapeutic boundaries.

The types of VR used varied in degree of immersion, interactivity, and personalization. Although some interventions leveraged avatar-based social interaction and co-creative participation, others focused on passive relaxation, physical activity, or aesthetic immersion. Most studies adopted structured sessions and validated outcome measures to assess emotional and social well-being, revealing a promising landscape of approaches. This thematic diversity underscores the adaptability of VR for different user profiles and intervention goals within older adult populations.

The articles employed a wide range of technological solutions to implement virtual reality (VR) interventions targeted at improving the emotional and social well-being of older adults. These technologies included head-mounted displays (HMDs), software platforms for individual and social experiences, tracking devices, audio enhancements, and custom-built environments adapted for elderly users. This technological diversity reflects both the rapid evolution of VR hardware and software in recent years and the experimental nature of many of the interventions designed for older populations.

A significant number of studies used immersive HMDs to deliver VR content, particularly those that aimed to induce a strong sense of presence or realism. The Oculus Rift was one of the most frequently adopted devices due to its robust tracking capabilities and immersive fidelity, appearing in the work of Baker et al. in several publications [15, 14, 18, 16, 17]. These studies explored avatar-mediated communication and co-designed social VR environments, utilizing the Oculus Rift in combination with platforms such as AltspaceVR and custom Unity-based applications to enable participant interaction. The same device was used in avatar interaction sessions lasting several months, offering participants a high level of embodiment and responsiveness through precise motion capture.

Oculus Quest 2 was another widely used headset, particularly favored in more recent studies for its wireless nature and relative ease of use. Kalantari et al. [9] used Oculus Quest 2 to allow geographically separated participants to connect in immersive environments, supported by integrated microphones and external audio devices such as Sony SRS-RA3000 speakers and Blue Yeti microphones for higher sound fidelity. This combination ensured better voice transmission and audio presence in multi-player settings. Qiu et al. [29] used the same device to perform a VR-assisted Tai Chi intervention over six months. The headset allowed participants to follow guided routines in a synchronized and embodied manner, combining visual feedback with body tracking to support therapeutic movement.

The Oculus Go, a standalone headset with simplified controls, was used in several studies that aimed to conduct more passive or observational VR interventions. Chaze et al. [22] selected this device for its lightweight design and user-friendly interface in a long-term care setting. Similarly, Graf et al. [25] used Oculus Go to deliver a forest walk simulation accompanied by a virtual dog and simple mini-games, aiming to improve mood through a naturalistic and low-interaction environment. The study by Appel et al. [21] also utilized this device to present 360° natural scenes in a feasibility study, demonstrating strong acceptance even among participants with cognitive impairments.

Samsung Gear VR, which uses Samsung smartphones as display and processing units, was used in earlier studies where cost-effectiveness and accessibility were critical. Lin et al. [26] compared Gear VR with traditional television viewing in a relaxation-based travel simulation, while Appel et al. [21] included it as part of a multi-device study setup. The ease of use of this headset made it particularly suitable for passive viewing interventions focused on reminiscence or affective modulation. Gruber et al. [20] likely employed a similar configuration to deliver 360° video content in a randomized controlled trial in multiple nursing facilities.

HTC Vive was deployed in studies that required accurate positional tracking and interaction fidelity, such as in avatar-based social VR and co-creation tasks. Baker et al. [15, 17] used HTC Vive's room-scale tracking capabilities to allow participants to move and interact naturally with virtual elements. These studies integrated the headset with Final IK for inverse kinematics and OVRLipSync to provide synchronized lip movement during conversation, enhancing communication realism.

Leap motion sensors were used in some interventions to provide hand tracking without the need for handheld controllers. Liang et al. [10] incorporated this technology into a custom metaverse environment, allowing participants to interact with objects and avatars using natural hand gestures. Similarly, Kosti et al. [19] designed an art-driven VR village where gesture recognition was a key element to allow participants to express creativity and navigate virtual space. These environments were hosted on platforms compatible with the Unity and WebXR standards.

Several interventions used semi-immersive or non-HMD solutions. Wang [30] used the Uniigym semi-immersive VR system to deliver group-based physical exercise. This setup consisted of a large screen, motion tracking camera, and speaker system, which enabled participants to engage in full body movement exercises in a communal setting. The lack of HMD reduced accessibility barriers while still providing interactive feedback. Lin (2017) [27] also used a large screen setup in some conditions, comparing it with HMD-based experiences delivered via Rendever VR systems.

The study by Fan et al. [28] combined virtual 3D gardening experiences delivered on desktop VR systems with real-world horticultural tasks. The virtual component included a customizable gardening environment viewed from a desktop monitor and navigated with mouse and keyboard, offering lower immersion but greater control for participants unfamiliar with HMDs. This hybrid approach allowed cognitive stimulation through interaction while minimizing motion sickness and fatigue.

Some studies incorporated customized environments and content developed specifically for the intervention. Baker et al. (2020b) [16] created a virtual classroom 'School Days' using Unity3D, designed based on participant feedback to support reminiscence through environmental cues. Participants interacted via avatars in a multi-user setting. Kalantari et al. [9] developed a travel-based social VR environment with embedded mini-games and spatialized audio to encourage collaboration. The environment was accessible through Oculus Quest 2 and featured custom designed visual assets to mimic recognizable cultural landmarks.

Wei et al. [11] developed a multiplayer virtual reality environment to play Chinese chess (Xiangqi), integrating a game engine with real-time voice communication and a culturally relevant design. The system was optimized for quick sessions on Oculus Quest devices, with audio-visual customization features to enhance participant comfort. The study by Xu et al. [12] also emphasized high-fidelity avatar design in a multi-site qualitative study, ensuring that avatars matched user characteristics and preserved identity cues, likely using Unity-based systems with support for advanced animation rigs.

Dinet et al. [33] used guided VR walks for relaxation and reflection, incorporating 360° video content accessed via Oculus Go and narrated scripts to provide structure. Similarly, Oppert et al.

[24] delivered immersive virtual tours using single-player VR, likely using lightweight mobile VR headsets to ensure usability among older adults unfamiliar with technology.

Faw et al. [32] presented participants with virtual symphonic concert experiences, likely using Oculus Go or similar HMDs for passive immersion. The VR experience included multi-angle virtual cameras placed onstage, combined with high-quality audio to simulate the experience of attending a live performance. Korsgaard et al. [31] conducted a mixed reality dining study, integrating VR visuals with real food and ambient sounds to simulate communal dining, using HMDs and video pass-through functions.

Chaze et al. [22] reported on the use of VR applications focused on Canadian landscapes, suggesting the use of preloaded content accessible through standalone HMDs. These devices allowed residents of long-term care facilities to experience familiar or meaningful places without physical travel. Li et al. [13] implemented a virtual cottage environment for group-based activities, likely using custom Unity-based multiplayer applications accessed via standalone VR headsets or projection-based systems depending on participant needs.

In general, technological implementations show a trajectory from stationary passive HMD systems to more interactive, social, and customized VR applications. Most interventions used off-the-shelf hardware adapted with tailored software, while several pushed the boundaries through co-design and cultural integration. This technological diversity reflects both the adaptability of VR and the importance of aligning hardware and software choices with user capacities, intervention goals, and research contexts.

2.2.4 Reported outcomes and measurements

The 25 empirical studies included in this review used a variety of quantitative and qualitative methods to assess emotional and social well-being outcomes in older adults exposed to virtual reality (VR) interventions. Despite methodological heterogeneity, all selected studies provided data relevant to constructs such as loneliness, social connection, affect, mood, quality of life, and depression. These were typically measured through validated self-report instruments or researcher-designed protocols and, in some cases, supplemented with behavioral observations or physiological markers.

Kalantari et al. [9], who found high user engagement and intention to reuse VR ($M = 4.18/5$), and Lin et al. [26], whose intervention reduced loneliness and depression in assisted living residents. Gruber et al. [20] reported a one-point increase in subjective happiness ($SD = 1.62$) after two days of 360º video VR sessions. Korsgaard et al. [31] observed significant improvements in mood ($p < .05$) after mixed-reality social meals, while Appel et al. [21] recorded positive affect and relaxation using PANAS and usability metrics, with 76% of participants willing to reuse technology.

Qiu et al. [29] conducted a 6-month RCT in which VR-assisted Tai Chi significantly reduced depressive symptoms, as measured by the GDS. Wang [30] reported improvements in WHOQOL-OLD domains such as autonomy and social participation after semi-immersive VR exercise, although the effects were not sustained at 3 months of follow-up. Wei et al. [11] demonstrated increased social connectedness through multiplayer cultural gaming, while Lin [27] and Graf et al. [25] found increased emotional well-being and positive affect using PANAS scores before and after the sessions. Restout et al. [23] showed statistically significant reductions in depression ($p = .015$) and anxiety ($p < .001$) after eight immersive VR relaxation sessions, along with high satisfaction ($M = 8.7/10$).

Beyond this core group, other studies provided complementary findings. Liang et al. [10] implemented a metaverse-based social VR center and reported improved mental states through qualitative feedback. Baker et al. [15] used participatory co-design sessions and noted that older adults valued social avatars and perceived VR as a tool for meaningful reminiscence. In [14], avatar customization and communication features were seen as critical for engagement. The longitudinal study by Baker et al. [17] found that over five months, participants became more expressive and emotionally connected through avatar-mediated VR, a finding also supported by [16], where the reminiscence environment of the "School Days" led to better reflection and connection.

Chaze et al. [22] reported that VR experiences offered cognitive stimulation and promoted social and emotional well-being. Oppert et al. [24] found that a single 30-minute 360 tour session improved comfort and reduced perceived isolation. Lin et al. [26] recorded higher satisfaction scores in VR than in TV conditions ($M = 6.13/10$). Faw et al. [32] used virtual symphonic concerts and observed positive emotional reactions and a strong sense of presence. Kosti et al. [19] emphasized cultural engagement, with participants appreciating the creative and social dimensions of their art-driven virtual village.

Li et al. [13] demonstrated significant improvements in flexibility ($\eta^2 = .109$), group integration ($\eta^2 = .141$), and proactivity ($\eta^2 = .104$) over four weeks of multiplayer VR activities in nursing homes. Fan et al. [28] combined VR 3D gardening with hands-on horticulture and found increased self-esteem ($\beta = 2.18$, $p = .005$) and mastery ($\beta = 1.23$, $p = .039$), using a generalized estimating equation (GEE) model. Xu et al. [12] showed that interpersonal compatibility in avatar-mediated interactions influenced social presence and engagement. Dinet et al. [33] reported significant qualitative improvements in perceived loneliness and mood after immersive guided walks and relaxation sessions.

The collected evidence points to several recurring themes in the literature. Multi-user social VR environments were more frequently associated with reports of increased emotional and social connection. Interventions that incorporated codesign methods or culturally relevant content (e.g. [16, 19, 11]) achieved stronger engagement and perceived meaningfulness. Aesthetic and leisure-oriented interventions (e.g. [22, 20, 32]) consistently improved mood, although typically with short-term effects. The presence of facilitators or staff was also crucial to implementation success, especially in institutional or long-term care settings (e.g. [21, 13, 23]).

The superior effectiveness of multi-user social VR environments in promoting emotional and social well-being was consistently demonstrated across several interventions. Kalantari et al. [9] implemented a partner matching design in geographically distant older adults, where social presence and shared activities led to high levels of engagement and positive feedback. Liang et al. [10] developed a metaverse-inspired virtual center, which allows elderly participants to socialize in group-based scenarios. The structured nature of this social VR setting, combined with the emphasis on interaction, contributed to improved mental states and positive usability evaluations. Similarly, Xu et al. [12] found that realistic avatar-mediated dyadic interactions enhanced perceptions of social presence and interpersonal engagement. Wei et al. [11] took advantage of culturally familiar content, Chinese chess, to create a social multiplayer VR space, resulting in increased perceived connectedness through meaningful and familiar gameplay. Baker et al. (2021) [17] further underscored the strength of prolonged social VR use, showing that regular engagement in avatar-based environments improved expressiveness and interpersonal communication over a period of five months.

Studies that incorporated co-design methodologies or culturally tailored content tended to yield higher engagement and perceived relevance. Baker et al. (2019a) [15] and (2020b) [16] developed interventions in which older adults were directly involved in the creation of virtual reality social environments and reminiscence scenarios. These participatory designs allowed users to shape the virtual context to align with personal and cultural memories, promoting stronger emotional resonance and social connection. Kosti et al. [19] also adopted a co-creative framework, developing a culturally inspired virtual village through collaborative design sessions with older adults. The result was a highly appreciated and emotionally significant VR environment that supported artistic self-expression and cultural identity. Wei et al. [11], by embedding a traditional game in the social VR format, similarly capitalized on cultural familiarity to enhance participant motivation and comfort.

Short-term mood improvement was frequently observed in aesthetic and recreational VR interventions, particularly those using passive or semi-interactive experiences. Gruber et al. [20] reported increased happiness after only two short sessions of 360° video content, particularly when the scenes involved people or animals. Appel et al. [21] found that one-time VR exposure to natural scenes resulted in relaxation and enjoyment among frail institutionalized participants. Graf et al. [25] demonstrated a moderate improvement in positive affect after a single 30-minute interactive forest walk in VR. Restout et al. [23] implemented an immersive VR intervention of eight sessions using 360° nature videos in a nursing home context. The study reported a statistically significant reduction in anxiety ($p < .001$) and a more modest borderline effect on depression ($p = .067$), along with high participant satisfaction ($mean = 8.7/10$). Although anxiety outcomes improved clearly, caution is warranted when interpreting depression results due to weaker statistical support. The importance of trained facilitators was also evident, especially in institutional contexts. Lin [27] and Lin et al. [26] both conducted controlled trials comparing VR with television experiences, with facilitators guiding participants through the content. These studies noted better emotional outcomes in the VR groups, which may in part reflect the impact of structured delivery and technical support. Chaze et al. [22] conducted multiple sessions over two weeks in long-term care facilities, emphasizing emotional and cognitive stimulation, facilitated by staff supervision. Li et al. [13] implemented group-based VR activities with nursing home residents, where facilitators helped manage interaction and ensured accessibility. In all of these cases, trained personnel played a crucial role in supporting participant adaptation, troubleshooting technological issues, and enhancing the general sense of safety and confidence among users.

Taken together, these findings suggest that social and co-created VR interventions are not only more engaging but also more effective in promoting meaningful interaction and emotional resonance. Passive or aesthetically focused experiences, while impactful in the short term, may benefit from repetition or integration into broader psychosocial programs. Finally, institutional interventions are most effective when accompanied by facilitation strategies that address the cognitive and physical needs of older adults, ensuring accessibility and maximizing potential benefits. In general, the outcome measures used in the studies, ranging from standardized psychometric tools (PANAS, GDS, WHOQOL-OLD) to customized usability metrics and qualitative reports, offered consistent evidence of the positive psychosocial potential of VR for aging populations. However, the heterogeneity in measurement instruments, intervention types, and reporting transparency highlights the limitations of drawing generalized conclusions in a scoping review context.

2.3 Discussion

This review suggests that although VR research for older adults is rapidly expanding, the field remains fragmented and lacks a unified theoretical foundation for long-term psychosocial impact. This growth is driven by the urgent need to address the challenges of the aging global population and the ongoing technological advancements. The ensuing discussion transcends a mere enumeration of findings; it constructs a critical narrative that cohesively connects studies, identifies emerging patterns, keenly examines methodological and conceptual disparities, and, most importantly, proposes a well-founded roadmap for future investigations.

The comprehensive analysis of 25 articles on Virtual Reality (VR) applications for the elderly reveals a dynamic and expanding research and intervention domain. To synthesize the main identified patterns, Table 2.2 summarizes these key themes and insights.

Theme	**Key Findings**
Mood and Emotional Well-being	VR experiences consistently evoke positive emotional states such as relaxation, happiness, and enjoyment in older adults.
Social Connection and Isolation Mitigation	VR demonstrates significant potential to foster new social interactions and connections, particularly for older adults, by providing a supportive environment for community building.
Usability and Accessibility in VR Adoption	The intuitive design, ergonomic hardware, and adaptation to older adults' specific motor and cognitive capabilities are crucial for effective VR implementation and acceptance.

Table 2.2: Key themes and findings.

There is consistent evidence that VR can affect older adults' emotional states, but the nature and depth of this impact vary considerably depending on the design of the experience. Passive content, particularly 360 videos of nature or familiar environments, has shown reliable effects in producing momentary relaxation, sensory pleasure, and psychological relief, especially in institutional settings where routine and sensory deprivation are common [20, 25, 23]. These effects are typically mediated by mechanisms such as attentional distraction, perceptual immersion, and temporary cognitive disengagement. Chaze et al.[22] reinforce this by demonstrating pain relief through VR, rooted in attentional redirection, while Lin et al.[26] and Fan et al.[28] expand emotional outcomes to include higher self-esteem and reduced depressive tendencies. However, while promising, these benefits can be shaped as much by novelty or contextual framing as by the content itself, as Appel et al.[21] cautioned.

More participatory or symbolic VR experiences appear to produce deeper and potentially more lasting emotional effects. Qiu et al.[29] showed that embodied engagement through movement-based practices such as Tai Chi led to reductions in depressive symptoms, suggesting that active participation enhances affective impact. Faw et al.[32] and Kosti et al.[19] emphasized the power of aesthetic and co-creative immersion to evoke complex emotional responses,nostalgia, self-expression, and transcendence, by activating personal and cultural memory. These studies point to a shift in the emotional mechanisms at play: from passive distraction to symbolic integration and emotional agency. Although passive VR offers a low threshold entry point with short-term mood benefits, more expressive and interactive formats may be necessary for long-lasting psychological gains.

Research increasingly supports VR's potential to mitigate social isolation among older adults, not simply by enabling contact, but by redefining how social connection is experienced in later life. Unlike conventional communication tools, VR offers immersive and disinhibiting environments where older users can interact in ways that transcend physical limitations and social inhibitions. Studies such as Kalantari et al.[9] and Baker et al.[14] highlight the viability of VR as a communication medium, but also point to deeper dynamics: the capacity of immersive environments to foster affective copresence, encourage spontaneity, and reduce psychological barriers to self-expression. Avatars, as shown by Baker et al. [17], may function not only as proxies, but also as expressive extensions of identity, enabling users, especially those who are introverted or self-conscious, to interact more confidently and authentically. This suggests that social VR fosters a kind of relational flexibility that is rarely possible in real-world institutional settings.

In addition, interventions grounded in reminiscence, such as those designed by Baker et al.[15, 16], demonstrate how VR can create symbols-loaded spaces that trigger autobiographical memory and shared cultural reference points. These environments (e.g., old-style classrooms or familiar neighborhood scenes) do more than entertain; they scaffold connection through nostalgia and shared identity, reactivating dormant social scripts and relational roles. Similarly, shared activities such as virtual tours or Chinese chess[24, 11] serve not just as diversions, but as structured rituals that give meaning and rhythm to social contact. Xu et al.[12] and Dinet et al.[33] emphasize that carefully designed environments, with intuitive interaction, ambient social cues, and shared goals, can foster a sense of belonging even in remote or asynchronous settings.

However, this optimistic view warrants scrutiny. Although the affective and symbolic depth of social VR is promising, the risk of superficiality or performative interaction persists, especially when the content lacks cultural relevance or emotional resonance. Furthermore, the idealization of VR as inherently inclusive ignores critical issues of access, technological fluency, and individual readiness for embodied digital presence. Korsgaard et al. [31], for instance, found that even socially framed VR experiences (e.g., shared meals) may struggle to replicate the subtle social synchrony and emotional nuance of in-person interaction.

Together, the literature suggests that VR can indeed foster meaningful social connections, but only when designed with sensitivity to the psychological, cultural, and symbolic dimensions of aging. Its true strength may lie not in substituting face-to-face interaction but in creating new forms of mediated intimacy that feel authentic, emotionally resonant, and personally relevant. This demands a shift from viewing VR as a mere communication platform to understanding it as a relational ecology, where social presence emerges not from proximity alone, but from design choices that honor memory, identity, and emotional texture.

A central methodological divergence in VR interventions for older adults lies between single-user and multi-user formats, each offering distinct benefits and limitations. Single-user approaches, such as those employed by Gruber et al.[20], Chaze et al.[22], and Lin [26]—are often easier to implement, less demanding in terms of technical infrastructure, and highly effective in providing immediate emotional relief. These interventions typically rely on passive content (e.g., 360 nature videos) that can induce relaxation, reduce anxiety, and offer a temporary sense of escape, particularly valuable in institutional settings marked by monotony and limited stimulation. However, their inherently solitary nature and limited interactivity make them susceptible to habituation and reduced long-term engagement. Emotional gains may be driven more by novelty than by sustained connection, and without evolving content or personalization, these effects risk fading over time.

Multi-user or socially interactive VR such as in the work of Kalantari et al.[9], Wei et al.[11], and Baker et al.[16] offers a more robust foundation for enduring psychosocial benefits. These interventions leverage shared environments, avatar-mediated interaction, and culturally resonant scenarios (e.g., reminiscence-based virtual classrooms or games) to foster empathy, co-presence, and a renewed sense of identity. Although technically more complex and dependent on user readiness, social VR tends to produce deeper engagement, particularly when users can actively contribute to the experience. It is especially well-suited to combating loneliness, as it creates opportunities for mutual recognition, conversation, and the formation of new relational routines. Importantly, several studies (e.g., Xu et al.[12], Baker et al. [18]) demonstrate that older adults can adapt to these environments over time, gradually building confidence and fluency in social interaction.

Hybrid designs, as explored by Fan et al.[28] and Oppert et al.[24], reveal that the line between individual and social engagement is not fixed. Passive experiences can act as gateways to more participatory use when scaffolded with human facilitation or contextualized within shared real-world activities. This adaptability is crucial: rather than prescribing a universal format, interventions must evolve with the user's emotional readiness, cognitive abilities, and social needs.

Although both approaches have merit, the evidence suggests that multi-user, socially oriented VR offers a more sustainable impact on the well-being of older adults. Its ability to foster belonging, reciprocity, and meaningful dialogue gives it a unique advantage in addressing not only transient mood states but also the deeper structural roots of loneliness and social disconnection. However, this potential can only be realized through thoughtful design, adequate support, and sensitivity to the evolving capacities of users. As such, the future of VR for older adults lies not in choosing between solitary or social formats, but in developing adaptive systems that prioritize social inclusion while accommodating diverse entry points.

Another underexplored yet conceptually rich dimension of VR interventions lies in the transition from passive to active engagement and the creative affordances that facilitate this evolution. Although passive experiences, such as 360 videos or guided relaxation environments, are often used as initial entry points due to their low cognitive and motor demands, they risk remaining affectively shallow if not scaffolded toward more meaningful participation. Studies by Gruber et al.[20] and Restout et al.[23] show that passive VR content can induce immediate mood improvement and emotional comfort. However, without opportunities for expression, co-creation, or feedback, these experiences may offer limited psychosocial depth and are unlikely to sustain long-term engagement. In contrast, interventions such as those developed by Kosti et al.[19] and Faw et al.[32] illustrate how creative and artistic modalities can reconfigure older adults from passive observers to active participants and emotional agents. Kosti's co-creative workshops demonstrated that VR could awaken dormant expressive capacities and foster a sense of authorship and self-efficacy, particularly among participants with prior visual or artistic inclinations. Faw's exploration of aesthetic immersion revealed that symbolic and abstract environments, when thoughtfully designed, can evoke deeply personal emotional responses, such as nostalgia, transcendence, or connectedness to lost identities. These findings suggest that artistic engagement in VR is not a peripheral novelty but a central mechanism for emotional resonance and identity reinforcement, especially in later life.

However, despite their conceptual richness, such interventions raise important practical challenges. Artistic formats often resist standardization, complicating efforts to consistently evaluate impact between users or institutions. Their effectiveness may also depend heavily on individual expressiveness, cultural literacy, or prior exposure to creative practices that potentially exclude users with limited confidence, interest, or familiarity in such domains. Furthermore, emotional responses to symbolic content are highly subjective and context-dependent, posing difficulties for replication or scalability. As such, while artistic VR holds significant promise, its integration into broader care strategies requires careful attention to inclusivity, adaptability, and evaluative rigor.

Importantly, these artistic and co-creative approaches function as bridges—they gently ease users from consumption to participation, from solitude to connection. They also bypass traditional barriers such as technological anxiety or lack of literacy in games by focusing on meaning, narrative, and emotional texture rather than performance. However, they pose challenges: artistic content is often more difficult to standardize, evaluate quantitatively, or scale across institutions. In addition, its impact can be deeply subjective and vary widely between users. Still, in light of the limitations of purely passive consumption and the practical demands of multi-user coordination, these creative formats emerge as a promising middle path. They enable emotionally rich, personally relevant, and semi-structured participation, making them ideal candidates for phased or adaptive VR strategies. Future work should explore how these modalities can be integrated more systematically into long-term care programs and whether their affective impact can be reliably measured over time. The available evidence suggests that moving beyond passivity, without demanding full interactivity, may represent a critical design sweet spot to engage older adults in immersive and meaningful ways.

The literature consistently emphasizes the critical importance of usability and accessibility for VR adoption and effectiveness. For VR to be successfully integrated into the lives of older adults and deliver potential benefits, software interfaces and hardware design must be intuitively accessible and meticulously adapted to their specific physical and cognitive capabilities. Research by Baker et al. [15], Baker et al. [18], and Xu et al. [12] consistently identifies challenges related to intuitive navigation, hardware ergonomics, and the need for designs that accommodate varying motor and cognitive abilities. These studies underscore that such design considerations are not secondary, but fundamental prerequisites for successful implementation. Appel et al. [21] explicitly noted that VR feasibility for older adults depends on addressing usability concerns, especially for those with cognitive or physical impairments. Kosti et al. [19] and Gruber et al. [20] further emphasize the critical need to rigorously evaluate the usability of the VR system and the overall user experience for older people, indicating that user-centered design is paramount. Implicitly, the positive outcomes reported by Lin et al. [26], Graf et al. [25], and Chaze et al. [22] regarding the enjoyment and engagement of older adults with VR strongly suggest that the underlying systems were sufficiently usable and accessible to facilitate these positive experiences. This collective emphasis on user-centered and participatory design approaches is presented as the cornerstone to overcome barriers and ensure widespread acceptance and efficacy of VR technology among older adults.

Beyond these three strongly supported findings, other relevant themes, although not consistently supported by eight or more articles in this specific review, also provide valuable insights. The broader concept of co-design with older adults, extending beyond mere usability to encompass creating highly relevant and emotionally engaging interventions, remains a crucial practice. The specific impact of sensory immersion for relaxation, particularly through passive or nature-based VR experiences, on emotional regulation and reduction of anxiety or depression symptoms is a distinct and promising area. Furthermore, VR's potential as a therapeutic or cognitive tool to enhance cognitive function, beyond its impact on mood and social participation, and to improve functional autonomy, particularly within structured physical or mental health programs, is also a developing research area. Lastly, the use of social VR for reminiscence and narrative engagement, allowing users to revisit autobiographical memories and explore cultural identities, thus enriching emotional expression and social connection, represents a significant and valuable application. Although these areas may require more extensive investigation to reach the same level of widespread support as the top three findings, they undoubtedly offer important avenues for future research and development in VR for older adults.

Beyond emotional and social well-being, VR is increasingly investigated as a valuable tool for cognitive and physical health. Although less emphasized in this specific collection of articles, the evidence is promising. Studies such as the randomized controlled trial by Wang et al. [30], which examined the impact of VR exercise on quality of life, and the quasi-experimental study by Fan et al. [28], exploring VR combined with horticultural activities for psychological well-being, represent leading quantitative research with stronger methodological rigor. Wang et al. [30] report measurable improvements in quality of life, while Fan et al. [28] indicate benefits in domains such as self-esteem and mastery. These findings are encouraging, but the inherent heterogeneity of interventions (from structured physical exercise to therapeutic horticulture) impedes direct generalization and necessitates a more robust consolidation of evidence through systematic meta-analyses and additional randomized controlled trials focused on specific and clinically relevant outcomes. The capacity of VR to increase activity levels and engagement has also been noted in studies by Li et al., Chaze et al. and Baker et al. [13, 22, 18]. In particular, Li et al. [13] adopt a longitudinal and exploratory approach, investigating the impact of VR in nursing homes over time, suggesting that VR can be a sustainable strategy to promote long-term engagement. However, a persistent gap remains in direct comparisons between VR-mediated activities and traditional physical interventions regarding both clinical efficacy and cost-benefit, an area that requires more direct quantitative and comparative investigation.

A critical assessment of the implementation of VR for older adults reveals that technological sophistication alone is not sufficient to ensure effectiveness. Usability and accessibility are not peripheral concerns, but central determinants of adoption and impact. Participatory design studies and qualitative investigations by Baker et al.[15, 18] and Xu et al.[12] consistently emphasize the need for interfaces that accommodate the specific motor, cognitive and perceptual profiles of older users. Without intuitive and ergonomically adapted systems, even emotionally promising interventions risk rejection or superficial engagement. Moreover, as Chaze et al. [22] noted, while VR can reliably induce relaxation and distraction in structured settings, its long-term emotional efficacy remains uncertain. The fleeting nature of novelty-based effects points to the need for dynamic content, personalization, and graduated interactivity that evolves with user familiarity and interest.

This underscores a broader systemic implication: VR should not be deployed as a standalone tool, but as one component of an integrated psychosocial care model. Sustainable implementation requires infrastructural investment, staff training, and a supportive ecosystem that frames VR experiences within a continuum of care activities. In institutional contexts, where routine fatigue and under-stimulation are prevalent, embedding VR into regular therapeutic, recreational, or reminiscence practices, facilitated by caregivers or activity coordinators, may be crucial for sustained benefit. These findings call for a shift in focus: from isolated technological solutions to holistic, context-sensitive strategies that align with the lived realities and institutional constraints of older adult populations.

The acceptance of technology by older adults is an inherently multifaceted factor that extends beyond technical specifications. Baker et al. [18] underscore the paramount importance of perspectives from both residents and, crucially, nursing home staff. This reveals that VR acceptance is not only about hardware or software design, but also about its harmonious and sensitive integration into existing workflows and the institutional culture of care. The innovative 'new art-driven methodology' introduced by Kosti et al. [19] suggests that unconventional and creative approaches can unlock deeper and more authentic engagement, although their scalability and rigorous impact evaluation require further testing and validation. A significant gap in the current literature is the lack of systematic and in-depth investigation of adverse reactions, such as VR-induced dizziness or nausea (cybersickness). Although Gruber et al. [20] mention collecting data on 'side effects', the extent of discussion on proactive mitigation and actual prevalence in older populations with varying sensitivities and comorbidities varies considerably. This critical area requires more systematic investigation, reporting, and integration into design guidelines and intervention protocols.

The dual presence of qualitative and quantitative approaches represents a methodological advantage in this emerging field, but one that remains under-leveraged. Although qualitative studies uncover the nuanced mechanisms behind user experience and engagement, and quantitative studies offer outcome validation, the two rarely inform each other in a truly integrated framework. Future research would benefit from prioritizing mixed method designs in which qualitative insights directly inform the development of quantitative measures, thereby supporting a more integrated and explanatory understanding of the impact of VR on older adults. Their complementarity is evident: qualitative studies provide the necessary depth to uncover the 'why' and 'how' VR experiences affect older adults, critically forming future intervention design. Quantitative studies offer the breadth and rigor to measure effects and compare interventions. For example, detailed insights from Baker et al. [14] on avatar design motivations can and should guide the development of more effective VR interventions, which can then be rigorously tested for outcomes like depression, as investigated by Qiu et al. [29]. However, the intrinsic limitations of individual studies persist. Qualitative studies, while rich in ecological validity and capable of generating an in-depth understanding, are inherently exploratory, and their often small samples limit the generalization of the results. Their conclusions focus on understanding potential rather than statistically proven efficacy. Randomized controlled trials [20, 30] and quasi-experimental studies [28] are crucial to establish evidence of clinical efficacy. However, these often lack the depth to explain the underlying mechanisms or capture the rich subjective experiences of the participants. For example, Lin et al. [26] may demonstrate quantifiable benefits, but individual perception of these benefits is not the main focus. Their limitations often include relatively short intervention durations and inherent difficulty in controlling all outcomes-influencing variables. Korsgaard et al. [31]'s failure to find significant changes in energy intake highlights the complexity of measuring physiological outcomes in virtual environments and the need for more robust study protocols. A notable literature gap is the scarcity of truly integrated mixed-method studies, where qualitative and quantitative data are collected, analyzed, and crucially interpreted together for a holistic understanding. Currently, many articles are predominantly one type, and the other component serves only a secondary role.

It is important to clarify the methodological rationale that underpins the dual assessment of study quality and perceived benefit. Although this synthesis did not apply standardized critical evaluation tools, the quality evaluation of the study called the Strength of Evidence (SoE) was informed by widely recognized criteria, including methodological clarity, transparency in data collection and analysis, ethical conduct and general contribution of the study to knowledge. This approach is conceptually aligned with frameworks such as those proposed by the Global Spine Journal to define levels and the strength of evidence in applied health sciences [34]. Crucially, the SoE score was calculated independently of the benefit rating to preserve a clear distinction between methodological rigor and the magnitude of the impact of the intervention.

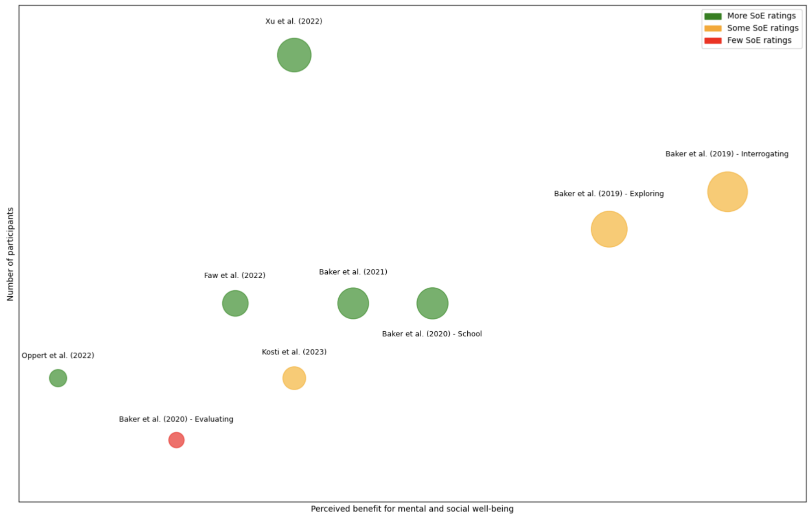

Figure 2.2: Perceived benefit in qualitative studies.

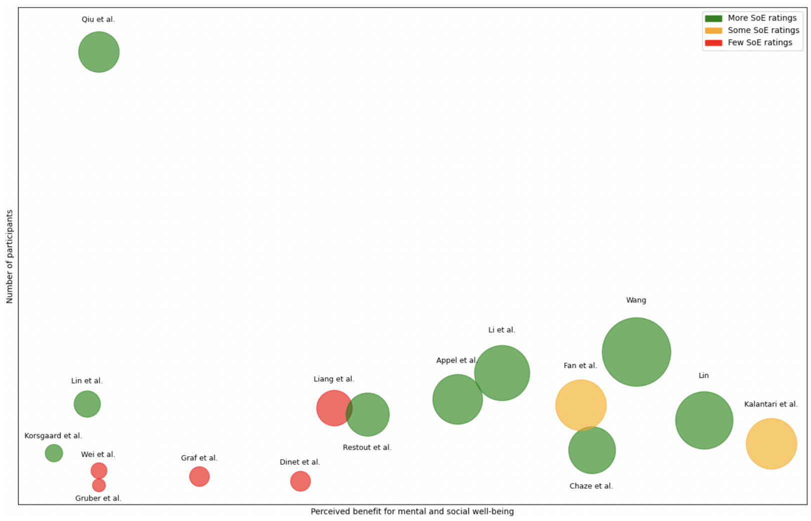

Figure 2.3: Perceived benefit in quantitative and mixed-methods studies.

In contrast, the estimation of perceived benefit, illustrated in Figures 2.2 and 2.3 is inherently more interpretative. There is no universal metric for quantifying the benefit of VR in heterogeneous designs. The reviewed studies employed diverse outcome measures, from thematic narratives and user satisfaction to standardized mood scales and physiological indicators. As such, benefit scores were derived through a structured synthesis of reported results, emphasizing the scope, depth, and clarity of perceived effects. Greater weight was given to interventions that demonstrated sustained emotional or social improvements, participant-reported transformation, or novel contributions, while short-lived, ambiguous, or narrowly framed outcomes were rated lower.

These figures are not intended as hierarchical rankings but as comparative heuristics. The position of each bubble reflects its reported benefit (x axis) and sample size (y-axis); the color encodes its methodological strength (SoE); and the size is proportionate to the combined influence of SoE, perceived benefit and participant count. This multidimensional representation allows for comparative insight while avoiding reductive scoring. Ultimately, this pluralistic framework underscores that meaningful contributions may arise from both qualitative richness and quantitative robustness, and that "benefit" should be understood contextually rather than universally quantified. It should be noted that the axes in Figures 2.2 and 2.3 use separate scales for benefit and sample size, reflecting the heterogeneity of the results and study sizes in each group, and should not be interpreted as directly comparable.

Although most studies cluster in the mid to high benefit range, particularly those rated as high quality, these scores should be interpreted with caution. Although the visual synthesis suggests broadly positive outcomes, it also risks obscuring critical differences in how the "benefit" is conceptualized and measured across diverse methodologies. Studies range from capturing subjective well-being and social connection to tracking cognitive stimulation or symbolic engagement. Thus, the appearance of clustering may flatten this heterogeneity.

Among qualitative studies, some with moderate SoE, such as Baker (2020) [18] and Baker (2021) [14], reported high benefit scores. Their success likely stems from immersive and socially engaging designs that resonated deeply with participants, despite not being the most methodologically rigorous in the sample. In contrast, Oppert et al. [24], despite a higher SoE rating, demonstrated minimal benefit, possibly due to the limited emotional activation provided by passive virtual tours.

In the quantitative and mixed methods subset, a wider spread in benefit scores is observed. A stronger correlation between SoE and benefit; however, several outliers challenge this trend. High-quality studies such as Korsgaard [31], Qiu [29], and Lin et al. [26] showed limited benefit, probably because their interventions targeted specific domains (e.g. eating habits, tai chi, exercise) without deeply engaging social or emotional dimensions.

In contrast, studies with only moderate SoE—Kalantari [9] and Fan et al. [28]—reported high benefits. These interventions emphasized emotionally rich, socially immersive experiences, such as interactive VR social spaces or horticulture-based VR, which produced a strong user-reported impact despite being less methodologically strict.

The largest bubble in the quantitative and mixed methods graph belongs to Wang [30], who combined semi-immersive VR exercise with longitudinal monitoring. Its high benefit reflects not only the sample size, but also the reach of the intervention in multiple outcome areas, including mood improvement, physical activation, and quality of life, highlighting its broad effectiveness.

However, the process of assigning a unitary benefit score in various epistemological paradigms invites reflection. Interventions focused on embodied affect or subjective experience are not always directly comparable to those centered on measurable change in behavior or symptoms. For example, transient mood improvements may reflect novelty effects or social desirability biases rather than lasting change. Meanwhile, deeper shifts in agency, identity, or belonging often captured in qualitative studies are difficult to quantify but highly relevant.

Moreover, the near absence of adverse outcomes (e.g. cyber-sickness, disengagement, or perceived irrelevance) raises the possibility of selective reporting or institutional optimism. In particular in feasibility trials conducted within care settings, structural pressures can lead to under-reporting of neutral or negative effects, contributing to an overly favorable portrayal of VR interventions.

Although low-quality studies tend to produce low benefits, the relationship is not strictly linear. Substantial perceived impact can arise from moderately rated studies when the intervention is strongly aligned with the social, emotional, or experiential needs of the participants. These findings reinforce the importance of contextual sensitivity and user-centered design when interpreting and implementing VR in later life.

In this light, Figures 2.2 and 2.3 should not be read as definitive impact rankings, but rather as heuristic maps that highlight visible patterns and tensions in the literature. Their value lies not in prescribing a hierarchy of outcomes, but in prompting deeper reflection on how 'benefit' is conceptualized, measured and experienced among aging populations.

Furthermore, this review highlights several crucial practical implications and imperative future directions for VR research and application in older adults. First, VR design for this population must be intrinsically inclusive and older-adult-centered, necessitating the systematic adoption of participatory and co-design methodologies from early development stages. Meticulous attention to hardware ergonomics, intuitive interfaces, and culturally and personally relevant content remains paramount. Second, the context of VR application is diverse. Although showing particular promise in nursing homes, as demonstrated by Baker et al., Chaze et al., Li et al., and Restout et al. [18, 22, 13, 23], offering an escape from routines and new socialization opportunities, its potential for independently living older adults, as studied by Oppert et al., Wang et al., and Fan et al. [24, 30, 28], is equally vast, requiring solutions that integrate seamlessly into daily life. Third, successful VR introduction and implementation require adequate training and support for both older adult users and their caregivers. The challenge of overcoming barriers to digital literacy and ensuring safe, effective and autonomous use of technology is fundamental.

For future research, the following strategic directions are imperative. There is an undeniable need for more large-scale randomized controlled trials with heterogeneous and diverse samples to confirm the effectiveness of the VR intervention in specific health and well-being outcomes, ideally with longer durations to assess the sustainability of the effect. Developing VR content for older adults requires a grounded approach informed by empirical evidence, particularly qualitative insights into user preferences, values, and capabilities. Translating this understanding into design decisions, ranging from narrative structure to complexity of the interface, can significantly improve the psychosocial and cognitive relevance of VR interventions, improving both engagement and outcome sustainability. Evaluating long-term metrics and investigating the sustainability of VR engagement are crucial in order to understand how benefits are maintained over months or years. Furthermore, research should explore cost-efficient and scalable implementation models for healthcare systems and care institutions, ensuring a wider reach of VR. The impact of VR on family dynamics and caregiver well-being (formal and informal) is an underexplored area of immense practical and social importance. Addressing older adult population heterogeneity is vital; more studies are needed to investigate VR effectiveness in specific subgroups, considering, for example, varying cognitive impairment levels, pre-existing health conditions, and cultural contexts, to ensure truly personalized and equitable interventions.

Although the potential of VR to improve social, emotional, physical and cognitive well-being in older adults is increasingly recognized, the field now faces the more pressing challenge of translating this potential into scalable, inclusive, and sustainable implementations. Rather than reaffirming its promise, future research must focus on overcoming persistent limitations: small samples, short intervention durations, and inconsistent methodological standards, by fostering convergence around robust mixed-method frameworks and longitudinal designs. Crucially, advancing this field depends not only on technological refinement, but on embedding VR within broader ecosystems of care that prioritize user-centered design, accessibility, and contextual integration. The objective is no longer to prove that VR works, but to ensure that it works meaningfully and equitably in real-world settings, contributing to aging experiences that are not only longer, but richer in dignity, connection, and personal agency.

2.4 Synthesis and Implications

This review identified recurring patterns in the way virtual reality (VR) interventions have been applied to promote emotional and social well-being in older adults. As discussed in the section Reported Outcomes and Measurements, the most engaging and emotionally resonant experiences were those situated in multi-user virtual environments involving culturally meaningful activities. These contexts supported stronger emotional involvement, a sense of presence, and perceived connectedness.

The analyses in subsections within the types of VR interventions further highlighted the relevance of participatory approaches. Interventions that involved co-design processes or adapted content to user memories, routines, or cultural backgrounds were generally met with higher engagement and acceptance. This reinforces the importance of designing VR not only as a technological solution but as a medium shaped by lived experience and user agency.

Passive and aesthetic VR formats, such as immersive 360° nature or artistic videos, were frequently associated with mood regulation and short-term emotional relief. However, as detailed in the Discussion, these effects were often limited in duration and rarely extended beyond the intervention sessions. Their value, while real, appears to be bounded by context, frequency, and the degree of interaction offered.

A recurring implementation factor in different settings was the role of facilitation. As explored in the Discussion section, the presence of trained staff or facilitators was crucial to ensure accessibility, technical fluency and emotional support. However, few interventions examined how this facilitation could be integrated into routine care in a sustainable manner.

Despite the encouraging results, several methodological challenges remain. The heterogeneity of the outcome measures, the absence of medium- or long-term follow-up in most cases, and the underrepresentation of participants with cognitive or physical impairments are limitations that restrict the generalizability of current findings. Furthermore, the lack of consistent evaluation intervals complicates the assessment of sustained impact and limits cross-study comparisons.

Future research should prioritize longitudinal studies with standardized psychosocial outcome measures and scheduled follow-ups. Comparative approaches, such as those proposed in the Discussion, can help determine how specific modalities (e.g., interactive versus passive, social versus solitary) perform across different user groups and contexts. Adaptive intervention models that evolve from low-barrier formats to more immersive interactive experiences may offer promising pathways for gradual engagement and digital inclusion. In addition, a clearer understanding of how to incorporate facilitation into existing care workflows is needed to support real-world implementation beyond experimental settings.

In conclusion, the findings synthesized in this research indicate that the value of VR in improving emotional and social well-being in older adults is strongly dependent on the social relevance of the experience, the degree of participatory design and the continuity of implementation. Rather than approaching VR as a standalone technological solution, the most effective interventions are those shaped by user needs, enriched with culturally meaningful content, and supported by integrated facilitation. These insights offer a structured foundation for advancing more context-sensitive and person-centered applications of immersive technologies in gerontological practice.

Chapter 3

Problem and Proposed Solution

This chapter presents a detailed examination of the problem addressed in this research and the proposed technical solution. Covers the foundational rationale, the conceptual and technological development of the virtual moderator, its implementation, and the considerations involved in its design and deployment.

3.1 Problem Definition

While the detrimental impact of loneliness in later life is well established, efforts to mitigate it through digital means remain fragmented and often insufficiently tailored to the needs of older adults. Traditional strategies, whether in-person or mediated by conventional digital tools, face persistent barriers related to mobility, or emotional disconnect. In recent years, Virtual Reality (VR) has emerged as a novel platform capable of delivering immersive, socially engaging experiences, yet its use in directly addressing loneliness remains underdeveloped.

Most VR-based interventions prioritize immersive content or guided activities, but few explicitly focus on fostering open-ended, peer-to-peer social interaction. Even within multi-user social VR environments, older participants may struggle with initiating or sustaining conversation, especially in the absence of natural social cues or facilitative structures. As a result, the potential of VR to alleviate loneliness through genuine human connection is not fully realized.

This gap points to the need for systems that go beyond visual immersion and actively support the interpersonal dynamics essential to meaningful interaction. Without tools to scaffold dialogue, reduce conversational friction, and encourage participation, social VR encounters may fall short of creating the sense of connection required to counteract loneliness.

This dissertation addresses that need by proposing a conversational moderation system designed specifically for social VR settings. By guiding the rhythm of interaction, prompting engagement, and supporting inclusive dialogue, the system aims to enhance the quality of social presence and, ultimately, contribute to the alleviation of loneliness among older adults in immersive environments.

3.2 Overview of the Proposed Solution

The solution proposed in this dissertation is the creation of an intelligent virtual moderator, driven by artificial intelligence techniques, to facilitate meaningful social interactions between older adults in a non-immersive virtual reality environment, a choice explicitly made to avoid the use of head-mounted displays (HMDs), given the participants' limited technical familiarity. This moderator acts as a dialogue facilitator, intervening discreetly and strategically whenever needed to maintain dialogue flow and avoid prolonged silences or awkwardness.

The moderation experience was built within a 3D environment created in Unity, where the moderator interacts with participants in real time via voice and avatar representation. According to specialized literature, an experience qualifies as virtual reality (VR) when it meets a set of fundamental criteria widely accepted by authors such as Slater and Wilbur [35] and Steuer [36]:

- **Computer-generated 3D environment:** the virtual scenario must be digitally constructed, enabling simulation of realistic or imaginary spaces;
- **Real-time interactivity:** the user must be able to interact with the virtual environment and receive immediate feedback on their actions;
- **Sense of presence:** the experience must induce in the user the subjective perception of being "inside" the virtual environment, with presence that can be physical or social;
- **Sensory immersion:** the system should involve the user's senses, fully or partially, reducing real-world influence.

In this application, the first three criteria are clearly met. The 3D environment is entirely simulated in Unity and allows all users to participate in a shared space. Interactivity is ensured through real-time voice communication between participants and the moderator, with dynamic system responses. The presence manifests itself as a social presence, as participants see the moderator's body in the virtual space and hear its synthesized voice, features that contribute to perceptual immersion [37, 35].

Sensory immersion is not fully present, as the experience runs on conventional screens without head-mounted displays (HMDs) or other immersive devices. According to the typology by Burdea and Coiffet [38], this configuration falls under non-immersive virtual reality. This approach offers significant advantages in practical implementation, experimental control, and ease of deployment in laboratory or home settings, while preserving the structural elements that define a VR experience.

The system combines multiple technological components: voice recognition, natural language processing (NLP), speech synthesis, conversational memory management, and avatar visualization. The architecture integrates these functionalities into a cohesive, responsive system capable of adapting interventions based on conversation content, the recorded history of participants (via STT), and the context of interaction.

Unlike traditional chat systems, the developed moderator does not impose a rigid script or take over the conversation. Its operation balances passivity and active intervention, stepping in only when collective silence persists or when directly addressed. The interventions also draw on pre-collected participant data (name, age, interests, origin).

To ensure user-friendliness and straightforward operation, the solution was designed for integration into a 3D virtual environment viewable on a standard screen. The presence of the moderator is visually reinforced by a 3D avatar with facial expressiveness synchronized with the voice of the system, promoting greater naturalness and social presence.

This solution aims to provide a balanced, fluid, personalized conversational experience leveraging emerging technologies to support the emotional and social well-being of older adults by creating a humanized, structured, technologically assisted virtual environment.

3.3 Development Methodology

The development of this system followed a rapid prototyping and iterative refinement approach. Rather than adopting a formal agile framework such as Scrum or Kanban, the process relied on a flexible cycle of building, testing, and progressively adapting the system in response to observed behaviors and identified shortcomings. Initial prototypes were developed in a textual format, allowing faster validation of the moderator's conversation logic before adding more complex voice components.

In the earliest stages, tests were conducted by simulating multi-user dialogues in a terminal environment, where the researcher acted as multiple participants to probe the system's response. This strategy made it possible to explore different conversation scenarios, including unexpected user inputs, conflict situations, and varying participation flows, with the goal of ensuring that the moderator remained respectful, coherent, contextually aware, and capable of handling edge cases.

Key issues addressed during these tests included the handling of prolonged silences, which initially caused the moderator to intervene too frequently or irrelevantly. This was resolved by implementing a collective silence timer with carefully tuned thresholds. Another relevant adjustment involved improving turn-taking logic: the system originally focused on a single participant, neglecting others in the conversation. To fix this, a rotating addressing mechanism was introduced so that the moderator systematically engaged with all participants while preserving their freedom to speak in any order.

Further iterations included enhancements in the moderator's linguistic style. At first, responses used informal second-person pronouns, which could be perceived as disrespectful by older adults. Prompts were then refined to adopt a third-person tone, culturally more appropriate in Portuguese. The system was also improved to recognize shared topics among participants using a simple chroma-based keyword detection strategy, supporting more meaningful group discussion.

Voice features were integrated after these textual tests were validated. This included audio capture, transcription, and speech synthesis, with additional verification of timing, lip-sync, and the transitions between moderator speech and participant microphones.

For testing the system in a realistic setting, both local and remote modes were trialed. A second collaborator, who was not a real participant but assisted by pretending to be a user, was involved to simulate multi-person interaction and verify correct behavior. Feedback was collected informally by observing conversation flow, technical performance, and moderator behavior, leading to multiple refinements over time.

In summary, the development strategy was not based on a rigid methodology, but rather on rapid prototyping and iterative improvement. This pragmatic approach was well suited to the experimental and exploratory nature of the project, enabling frequent adjustments to meet emerging requirements and ensure a user-centered, respectful, and contextually aware virtual moderator.

3.4 Database

The database is a central element in the functioning of the virtual moderation system. Structured as a .json file, it stores detailed information about each participant, such as name, age, city, interests, profession, favorite activities, and speech history. This data allows the system to adapt the moderator's behavior in a personalized way, generating more natural, empathetic, and socially relevant interventions.

During prompt construction of the language model, the system uses this information to contextualize responses, allowing the moderator to establish connections with experiences or interests previously shared by participants. This logic is managed through the LangChain framework, which also ensures thematic continuity throughout sessions by avoiding repetition and promoting conversational cohesion.

The history field, updated in real time with transcriptions generated by the Google Speech-to-Text API, enables the system to maintain individualized conversational memory, supporting more consistent and meaningful interventions.

In addition, the system automatically adapts to the number of participants defined in the database. Upon startup, it counts the registered profiles and dynamically creates the necessary processes to listen, transcribe, and respond, without requiring changes to the code.

The database works in tandem with LangChain (for memory management) and Chroma (for retrieving relevant topics). Without these tools, the system's memory would be significantly limited; with them, the moderator can access the full conversation history rather than only recent interactions. Because it is stored in an easily readable and editable format, the database allows users to easily add participants, update profiles, or reuse data in future sessions.

The database ensures the personalization, scalability, and continuity of the system and is essential to provide a fluid, coherent, and contextually adapted conversational experience for each user.

The database model presented in Figure 3.1 was designed to fully support the VR dialogue moderator system, capturing user-related information and the details of each interaction session. At its core, the User entity holds the participant's profile, including attributes such as a unique user identifier, name, age, city of residence, profession, and optionally the audio channel used during VR sessions. To characterize individual preferences and contexts, the User entity is connected in a one-to-many relationship to entities such as Interest, Hobby, Music, Family, and Tradition, each of which stores additional descriptive elements linked back to a specific user through a foreign key. The system also records the multiple sessions in which participants take part, represented by the Session entity, which stores a unique identifier and the scheduled date and time. Since each user can join multiple sessions and each session can have multiple users, a many-to-many relationship is established between User and Session through an intermediate entity called User_Session, which includes foreign keys referencing both User and Session. Furthermore, to log the actual conversational content, the DialogueHistory entity captures every utterance, referencing both the user who produced it and the session in which it occurred, while also including the position of the message in the sequence and its text. This enables a full reconstruction of the conversation timeline and ensures data integrity. In general, the ER diagram shown in Figure 3.1 illustrates a structured and normalized database schema that guarantees data consistency, supports scalability for future enhancements, and provides a solid foundation to analyze the effectiveness of the VR-based dialogue moderator.

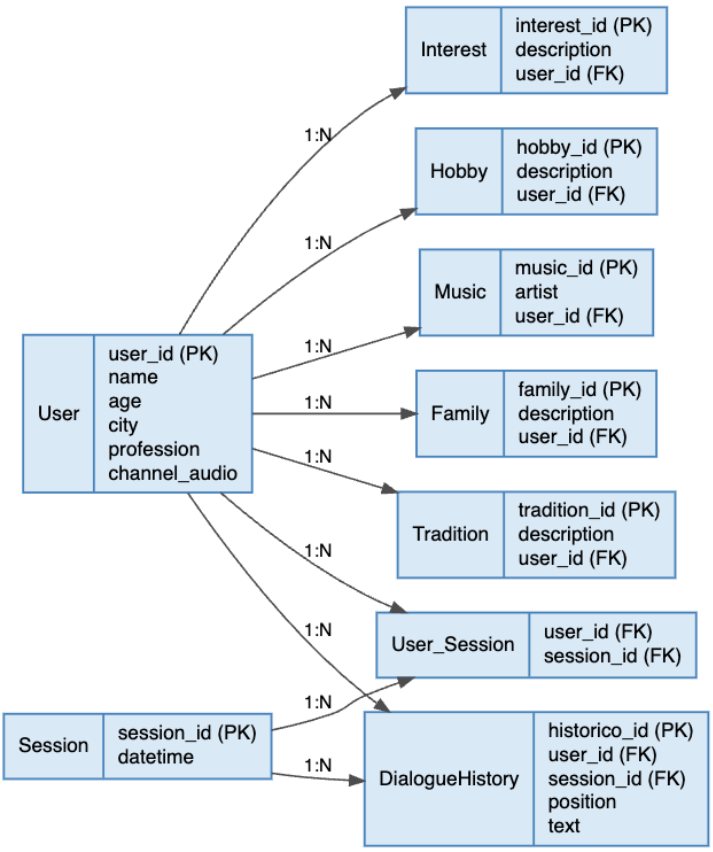

Figure 3.1: Entity-Relationship diagram representing the database structure for the VR Dialogue Moderator system.

3.5 System Architecture and Implementation Details

The system was developed using an empirical and iterative approach, centered on prototyping, hands-on experimentation, and progressive refinement, supported by continuous observation and qualitative analysis. The process began with a simplified text-based application designed to test the moderator interaction logic and evaluate the language model's ability to generate contextually appropriate responses.

The initial stages focused on simulating dialogues in a terminal environment with fictional participants. These simulations helped structure the moderator's behavior, identify conversational coherence issues, and assess the system adaptability in different interaction scenarios. One of the main challenges was finding a balance between the programed behavioral rules and the generative freedom of the model. Excess rigidity in rule-based coding led to artificial and predictable interactions, while relying solely on language models often resulted in vague or incoherent responses. Therefore, a hybrid architecture was adopted: the moderator's behavior is guided by well-defined prompts, while the code ensures basic conversational flow conditions, such as detecting prolonged silence or recognizing direct addresses.

Once the foundational principles were validated, the system evolved to incorporate real-time audio input and output. Voice capture was implemented using PyAudio, and speech transcription was handled via the Google Speech-to-Text API, configured for European Portuguese. The responses of the Moderator generated by GPT-4 were converted into speech using Azure Text-to-Speech, with the 'pt-PT-DuarteNeural' voice selected to maximize naturalness and familiarity.

Development followed incremental testing cycles, where each new feature was evaluated through complete session simulations or user interactions, accompanied by qualitative data collection and problem identification. The system logic was continuously refined: silence detection was improved, and interaction flows were adapted to accommodate different numbers of participants.

This iterative process resulted in a responsive and adaptable system capable of managing real-time conversations with fluidity, thematic coherence, and a communicative style that is both natural and empathetic. All technical decisions remained aligned with the main objective of the project: to create a technology-mediated interaction that is inclusive, meaningful, and emotionally relevant to older adults and helps reduce perception of loneliness.

The architecture of the virtual moderation system is modular and follows a client-server model. The server-side logic is implemented in Python, while Unity serves as the client, providing the 3D interface, audio playback, and user input handling.

At the core of the system is a continuous exchange of structured data between Unity and Python via TCP sockets. Unity sends the audio of the participants to the server through port 5050, which contains it in a message format that includes the participant's name between `<NAME>...</NAME>` tags and the corresponding audio encoded within `<AUDIO>...</AUDIO>`. The audio data are captured at 16 kHz and immediately normalized using the PyDub library (mono, 16 bit), ensuring compatibility with Google's Speech-to-Text

API. This API is configured for European Portuguese and provides transcriptions with automatic punctuation. These transcriptions are stored in real time in a local JSON file, updating the speech history of each participant.

Upon receiving valid speech input, the Python server compiles multiple incoming audio blocks to form complete utterances and transcribes them. Only valid speech (not noise or unintelligible input) resets the silence timer, which governs when the moderator should intervene. The timer is reset after each participant utterance and begins counting when silence resumes. If 10 consecutive seconds of silence are detected across all participants, the system triggers an automatic intervention from the moderator.

The moderation cycle begins when Unity starts playing the synthesized audio of the virtual moderator. At that moment, Unity sends a <BEGIN_AUDIO> signal to the Python server and deactivates the participant microphones using <MIC_OFF>. This also explicitly resets and freezes the silence timer to zero. Once playback ends, Unity sends <END_AUDIO> and simultaneously reactivates the microphones with <MIC_ON>. Only then does the timer start counting collective silence. If a participant speaks, a new <NAME>...</NAME><AUDIO>...</AUDIO> message is sent to the server, processed and transcribed, and the timer resets again. This logic ensures that the system only steps in when the dialogue naturally ceases, fostering respectful and non-intrusive moderation. The entire cycle is illustrated in Figure 3.3.

The textual interventions of the moderator are generated using the GPT-4 model via LangChain. Prompts are dynamically constructed using current conversation context and participant profile data (e.g., name, hobbies, topics previously mentioned). Strict guidelines are encoded to ensure that the moderator does not address the same person twice in a row, never imitates other participants, uses personal information respectfully, always uses third-person conjugation, and responds with sensitivity to potential misunderstanding or tension.

Furthermore, while the moderator is designed to intervene after 10 seconds of collective silence, it is explicitly programmed to override this delay and respond immediately if a participant mentions the word ’moderador’ during the session, ensuring responsiveness to direct appeals.

Once the GPT-4 response is generated, it is converted to speech using the Azure Text-to-Speech service (voice: ’pt-PT-DuarteNeural’). The audio is wrapped in <AUDIO>...</AUDIO> markers and sent back to Unity via port 5051. Unity receives this stream, creates a temporary file, plays it through an AudioSource, and synchronizes the facial animation of a 3D avatar with the audio using blendshapes, aiming to increase the perception of presence and embodiment in the environment.

The system includes two operational modes: local and remote. In local mode, all components are run on a single machine, with each participant using a distinct microphone. To enable speaker identification, microphones are configured through an aggregate audio device, where each input is assigned a specific channel. The system distinguishes who is speaking by monitoring audio activity on these separate channels; therefore, using different microphones is essential for participant differentiation in local mode.

In remote mode, Unity clients operate independently across machines. Before joining the session, participants must log into the LoginManager interface, entering a name that matches exactly with the entry in the local JSON database. This authentication ensures accurate mapping between participants, audio streams, and personalized memory history.

To support real-time coordination, Unity components such as MicrofoneManager, TCP-SpeechClient, and UnityMainThreadDispatcher ensure correct communication and visual updates. The WavUtility handles audio reconstruction into AudioClip objects for playback.

A parallel audio channel (port 5054) was initially tested to allow participants to hear each other directly, but performance issues, especially on low-bandwidth networks, led to significant buffering and delays. The solution adopted was to keep the intelligent moderator system active while suggesting the use of external VoIP platforms (e.g. Zoom, Teams) for direct user-to-user communication in distributed settings.

For remote operation over the Internet, port forwarding must be configured on the router that hosts the Python server. Public IP traffic on ports 5050 and 5051 must be forwarded to the local IP of the server (e.g., 192.168.1.100). In addition, OS-level firewall rules must be adjusted to allow for incoming TCP connections. On macOS, this can be done using pfctl or socketfilterfw; on Windows, via the Defender Firewall with Advanced Security. For added protection, these rules can be restricted to a predefined list of trusted IPs.

However, in local operation mode, the connection between the Unity client and the Python server must use the local IP address (e.g., 127.0.0.1 or the IP of the local network). Public IP is only required in remote configurations where the client and the server run on different networks.

Extensive testing was performed on both Windows and macOS environments to ensure compatibility, uncovering and resolving issues related to microphone permissions, script execution, and socket handling. These refinements contributed significantly to the robustness of the system and the cross-platform reliability.

The architecture diagram in Figure 3.2 organizes the system into four main processing modules that interact through defined data and control flows. The Unity Application block groups microphone audio acquisition, an AudioSource for playback and synchrony with the avatar, and a streaming client that forwards recorded audio to the server through a TCP socket. This guarantees that the voices of the participants are continuously captured and routed for analysis. The STT Module block represents the speech-to-text service, implemented using the Google STT API, which takes the incoming audio stream and returns transcribed text with punctuation. The text output is passed to the Decision & GPT-4 Logic block, which includes a dialogue parser to clean or segment user speech, a GPT-4-based core decision module, and logic to generate appropriate context interventions. This block also sends responses back to Unity via TCP using a structured message format. The TTS Module block covers the Azure text-to-speech component, transforming the GPT-4 textual output into natural-sounding speech. The synthesized audio is then routed back to the Unity AudioSource for playback to participants, allowing seamless turn-taking. In addition, a database block records logs of each session, including timestamps, user identities, session identifiers, the generated GPT-4 interventions, and the text and audio data exchanged. The diagram also highlights bidirectional TCP communication between the Unity client and the Python server for event coordination, guaranteeing real-time updates and consistent state synchronization across the pipeline. Overall, the figure illustrates how the components form a modular and scalable architecture in which each block fulfills a distinct role, from signal acquisition to semantic reasoning, to speech synthesis and feedback, enabling a responsive and socially coherent conversational environment.

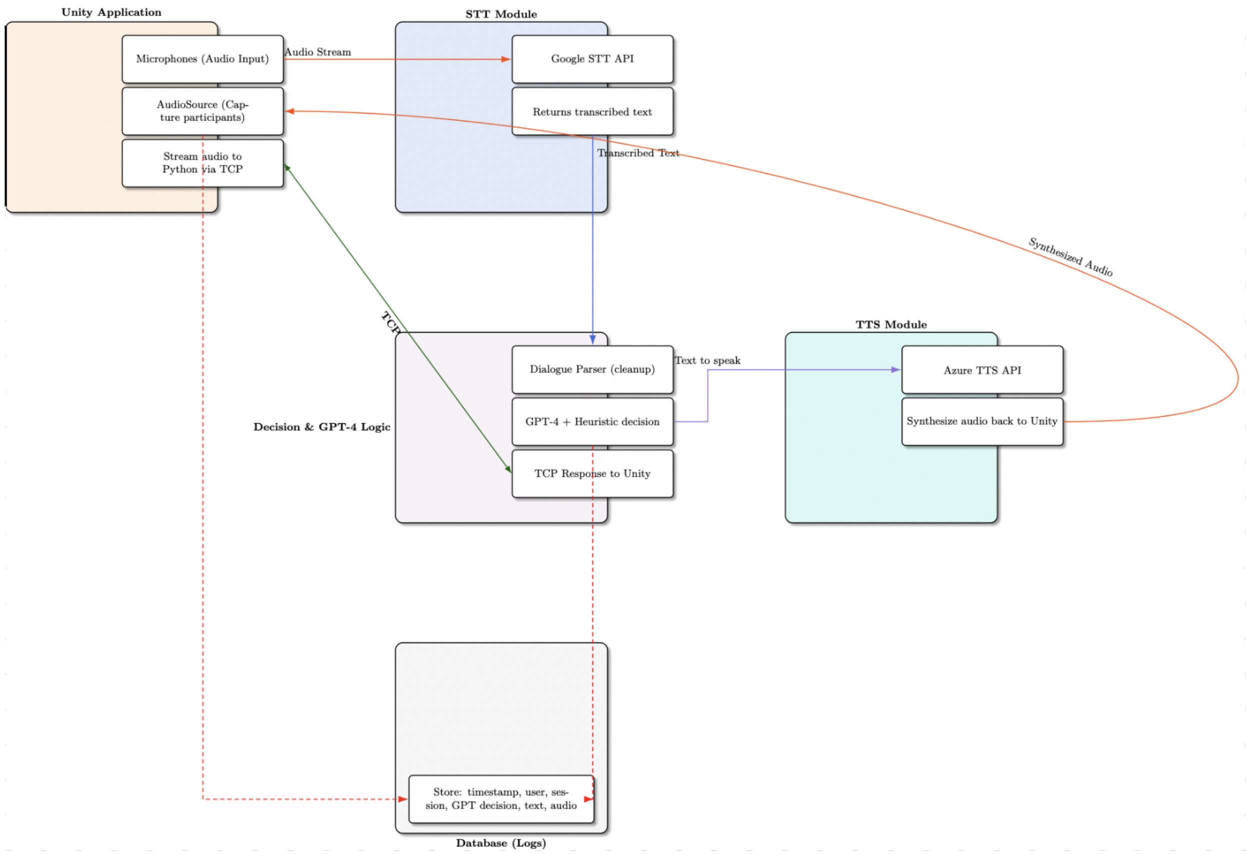

Figure 3.2: System architecture diagram illustrating the modular pipeline between Unity, Python-based decision logic, speech processing services, and the database.

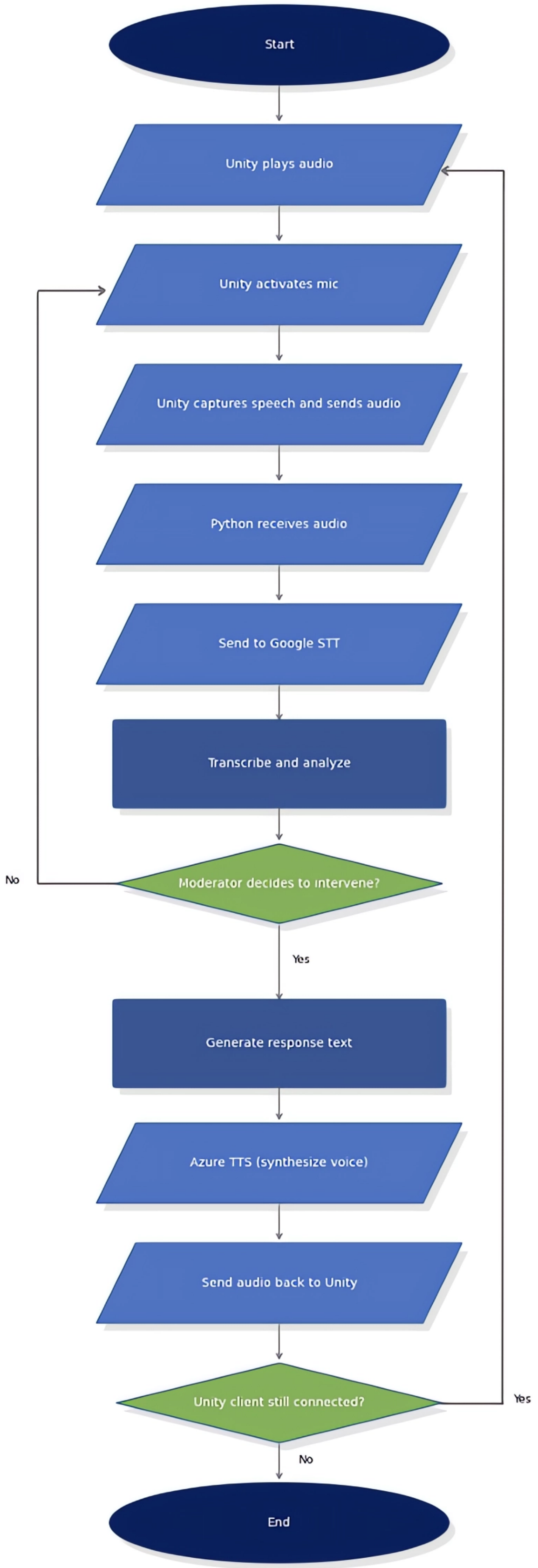

Figure 3.3: Representation of the system's conversational cycle

3.6 Avatar with Facial Animation and 3D Indicator

To enhance social presence and user immersion, the system includes a 3D avatar that visually represents the virtual moderator. The avatar was developed using the Convai platform and imported into Unity, where it is animated with BlendShapes to produce facial expressions and synchronized lip movements.

These animations are driven in real time by the audio waveform of the synthesized speech, allowing the avatar to mimic speech dynamics, including lip sync, eyebrow movement, and basic emotional expressions. This design improves the naturalness of the interaction and fosters user comfort and trust.

Additionally, a visual cue modeled after the well-known 'plumbob' (used in The Sims franchise) was placed above the avatar's head. This green 3D indicator is visible only when the moderator is speaking, helping participants quickly identify who is addressing them and reinforcing conversational turn-taking. The indicator is consistently illuminated and placed to avoid interference with other elements of the user interface.

Together, these visual enhancements support an intuitive and engaging virtual experience, contributing to the sense of realism and interpersonal connection within the non-immersive VR environment. Both the avatar and the visual indicator are illustrated in Figure 3.4.

Figure 3.4: Representation of the moderator's avatar

3.7 Data Protection and Use of External APIs

The system architecture was designed with strong data protection principles, especially considering the vulnerability of the target population. Only the minimum data required for real-time operation—short audio clips and anonymized transcriptions—are sent to external APIs, and no identifiable personal data are transmitted.

Three main APIs were integrated into the system: Google Speech-to-Text is used for transcription in European Portuguese, Azure Text-to-Speech handles natural voice synthesis, and OpenAI's GPT-4, accessed through LangChain, is responsible for generating context-aware dialogue.

All user profiles, including name, age, city, interests, and other attributes, are stored locally in a JSON database used solely for personalization. This information is never shared externally and is accessed exclusively by the moderator system during active sessions.

Communication with external APIs is performed over HTTPS, ensuring encrypted transmission. Locally, all data exchanges between the Unity client and the Python server are secured via TLS over TCP, providing integrity and protection against interception even in remote or distributed deployments.

Informed consent was obtained from all participants, who were fully informed about the functionality of the system, the data processing processes, and their rights to privacy and withdrawal. These practices are in line with the GDPR principles, emphasizing data minimization, transparency, and user autonomy.

3.8 Data Analysis Plan

The experimental protocol was designed to test the moderator system in a real-world care context with older adults experiencing varying levels of loneliness. Participants were recruited from a long-term care institution in Fafe, Portugal, where the study took place. The recruitment process and the full description of the participant profiles are detailed in Chapter 4.

To ensure contextual realism and participant comfort, five dyads (10 participants) were formed. Each dyad participated in three consecutive 30-minute sessions using the local mode configuration, enabling face-to-face interaction mediated by the conversational system. All sessions were supported by a familiar day care center staff member, who assisted with logistics, clarified procedures, and ensured emotional and technical support throughout.

The moderator operated in real time and relied on personalized profiles stored locally. Before sessions, participants completed a short intake questionnaire and basic demographic information was used to tailor conversational output. Identifiable data was not transmitted externally, and all personalization was handled securely within the local environment.

This study followed a mixed methods approach, integrating both quantitative and qualitative data to assess the impact of the intervention on perceived loneliness. The quantitative component focused on changes before and after the intervention, measured using two validated instruments: the original and revised versions of the UCLA Loneliness Scale. Data were organized into comparative tables to provide a detailed view of individual and group scores during the three-session intervention. For each participant, mean scores and standard deviations were calculated to assess variations in self-reported loneliness.

To support interpretability, various descriptive visualizations were generated, including box plots, histograms, and line graphs. These illustrated central tendencies, dispersion, and score trajectories, providing a comprehensive overview of the dataset and enabling a clearer interpretation of potential intervention effects.

Despite the exploratory nature of the study and the small sample size, paired sample t-tests were conducted to statistically compare the results before and after the intervention for both versions of the UCLA scale. These were supplemented by calculations of Cohen's d to estimate the magnitude of observed effects. However, the main focus remained on descriptive clarity and interpretation at the individual level.

The qualitative component consisted of open-ended feedback questionnaires collected after the final session. These responses were thematically analyzed to enrich the understanding of the subjective experiences of the participants, the perceived usefulness of the system, and suggestions for improvement. However, minimum statistical analysis was applied to the qualitative data, in accordance with the exploratory scope of this component.

The combination of quantitative rigor and qualitative insight provided a more holistic view of the effectiveness of the system, particularly with respect to its emotional and social relevance to older adult users.

Chapter 4

Evaluation, Results and Discussion

This chapter presents the main findings of the mixed-method intervention study, combining quantitative and qualitative analyzes to assess the impact of the system on participants' perceived loneliness and emotional experience.

4.1 Participant Recruitment and Sessions

Participants were selected based on self-reported loneliness and social isolation, measured by the UCLA Loneliness Scale and its revised version, both psychometrically validated tools for quantifying perceived loneliness. The goal was to identify individuals with different baseline levels of subjective isolation, allowing exploration of the effects of the intervention in a range of initial scores (low, medium, and high). From the eligible pool, participants were randomly selected to ensure variation in these scores and avoid sampling bias.

The final sample consisted of ten older adults with various levels of digital literacy but retained cognitive capacity and willingness to participate in supervised sessions. All participation was voluntary. The candidates were informed about the study's objectives, procedures, data protection practices, and their rights, including the right to withdraw at any time without penalty. Informed consent was obtained formally from each participant (Figures C.1 and C.2).

Before the intervention, participants completed the UCLA Loneliness Scale (original and revised versions), along with a short questionnaire used to personalize the system. The information was securely stored in a local database and used exclusively to tailor interactions, never shared externally.

The intervention was carried out in long-term care facilities of the Centro Social da Paróquia S. Martinho de Medelo (Fafe, Portugal), with full institutional cooperation. The sessions followed a local mode setup, in which two participants shared the same device, each with their own microphone. This configuration allowed natural face-to-face interaction and minimized cognitive and technical barriers, making the experience manageable for users unfamiliar with immersive technologies.

The participants were divided into five distinct pairs, each pair completing three consecutive sessions of approximately 30 minutes each. Sessions were scheduled weekly to allow time for rest and reflection between encounters. In total, 15 sessions were conducted. A trained member of the research team facilitated the sessions, provided technical support, and was available to intervene immediately in case of discomfort or withdrawal of participants.

After the final session, the UCLA Loneliness Scales were reapplied to assess potential changes in perceived loneliness. Participants also completed brief open-ended questionnaires and participated in short interviews to provide qualitative feedback on the impact of the system and its personal meaning.

Ethical considerations were embedded throughout the research process. All procedures respect international and national human research ethics standards, including those concerning data protection, anonymization, and the dignity of vulnerable participants. The study was carried out according to the ethical principles of the Declaration of Helsinki. Institutional approval was obtained from the National Network of Integrated Continuing Care (RNCCI), ensuring compliance with local governance for research involving older adults in care settings.

4.2 Qualitative Evaluation

Participants generally reported a positive experience with the virtual moderation system, describing it as both user-friendly and intuitive, even for those with limited technological familiarity. The moderator's voice was often characterized as clear and pleasant, while the visual presence of the avatar was said to enhance the sense of companionship throughout the conversation. Several individuals highlighted that they felt respected and valued, emphasizing the potential of the system to promote social engagement and stimulate dialogue.

Importantly, although the participants lived in the same residential care facility, many reported that they had rarely spoken to their assigned conversation partner prior to the study. Throughout the sessions, it became clear that the system played a catalytic role in fostering deeper connections. At the end of the third session, several pairs had established genuine friendships, with participants commenting on how they 'really got to know the other person' through the structured and supportive nature of the dialogue. This evolving dynamic may partly explain why the overall reception of the experience was so positive. Although the initial moments were marked by some shyness or hesitation, the participants gradually became more relaxed and the conversational flow improved significantly over time. The atmosphere grew noticeably lighter and more engaging with each successive session.

Most of the users reported feeling emotionally at ease during the sessions. The moderator's ability to recall personal topics, such as individual interests or previous remarks, was particularly well received, prompting comments such as 'it felt like it was really talking to me' and 'it remembered what I had said.' This personalization contributed to a strong sense of recognition and improved social presence. However, a few participants noted that the system occasionally repeated certain phrases or sentence structures, which somewhat diminished the spontaneity and made the interaction feel slightly artificial.

Regarding the conversational flow, some participants perceived a minor delay in the moderator's responses. Statements such as "it felt like it was thinking a long time before answering" or "sometimes the silence was a bit long" illustrate this impression. Although these pauses did not significantly detract from the experience, they were sufficiently noticeable to be cited as areas for potential improvement. The absence of visual or auditory signals during these moments may have contributed further to this perception of latency.

Most of the participants described the experience as positive and comfortable. In particular, 9 out of 10 individuals found it easy to communicate with their conversation partner and all participants (10/10) expressed that they felt at ease when talking and listening to. This indicates a strong sense of interpersonal comfort within the created environment.

Regarding the role of the virtual moderator, 9 participants believed that it contributed positively to the flow of conversation. All participants reported enjoying the experience overall. However, a participant remarked that interacting without the moderator could have been easier. Interestingly, despite favorable feedback, none of the participants felt that the moderator resembled a 'real person', suggesting that greater realism and social believability remain areas for improvement.

In terms of perceived impact, nine participants indicated that the experience had a positive effect on their lives, while one person described it as neutral rather than negative. Although the intensity of this impact varied, the overall trend points toward a modest emotional benefit.

Regarding usability, 6 of 10 participants reported some difficulty operating the system, which highlights the persistence of technical challenges, particularly among older users. When asked about future use, the responses were mixed: 6 participants expressed interest in repeating the experience and 5 indicated that they might consider using it with family or friends.

In general, the results suggest that the system provides a generally pleasant and engaging conversational experience, with a perceived positive influence on emotional and social well-being. Although the moderator was largely seen as supportive, improving its realism and reducing technical friction are key targets for future development.

Other components of the system were also well received. Automatic microphone activation performed as intended, avatar lip sync animations were considered expressive enough to accompany speech, and the triangular visual cue efficiently signaled when the moderator was speaking. The overall experience was viewed as safe, comfortable and innovative, often eliciting curiosity and a willingness to participate in future sessions.

Finally, some participants proposed adding occasional humor or lighthearted comments to future versions of the moderator, suggesting that such emotional nuances could enhance its social presence and promote a more relaxed conversational dynamic.

Much of this qualitative feedback was collected through a short questionnaire administered at the end of the intervention, which is included in the Appendix B for reference.

4.3 Pre-intervention Quantitative Evaluation

The quantitative analysis of the results obtained with participants was based on the application of the *UCLA Loneliness Scale* and its revised version, instruments originally developed by Russell, Peplau and Ferguson (1978)[39] and later refined by Russell, Peplau, and Cutrona (1980)[40]. These scales are widely recognized in the scientific literature as valid and reliable measures of subjective perception of loneliness. In the original version, scoring is straightforward, with all items rated in the same direction. However, in the revised version, the scoring system includes the reversal of specific items to control for response bias: Items 1, 5, 6, 9, 10, 15, 16, 19, and 20 are reverse-scored, as indicated by the authors [40]. This procedure ensures a more accurate reading of reported loneliness levels, allowing a clearer distinction between statements that are directly or inversely related to the construct being measured. The questionnaires used to assess perceived loneliness in the quantitative analysis are illustrated in Figures A.2 and A.3, which correspond to the original and revised versions of the UCLA Loneliness Scale.

To facilitate the interpretation of the results, score ranges were defined to classify the participants according to perceived levels of loneliness. These thresholds, although useful from an analytical perspective, were neither clinically validated nor officially proposed by the original authors of the scales.

For the *original UCLA Loneliness Scale* (total score range: 0 to 60), and the *revised UCLA Loneliness Scale* (total score range: 20 to 80), score interpretations were categorized into three levels of perceived loneliness: low, moderate and high. These thresholds, although useful from an analytical perspective, were neither clinically validated nor officially proposed by the original authors of the scales. The classification criteria adopted in this study are summarized in Table 4.1.

Scale	**Score Range**	**Interpretation**
Original UCLA Loneliness Scale	0–19	Low loneliness
(0–60 total score)	20–39	Moderate loneliness
	40–60	High loneliness
Revised UCLA Loneliness Scale	20–39	Low loneliness
(20–80 total score)	40–59	Moderate loneliness
	60–80	High loneliness

Table 4.1: Interpretation thresholds for the UCLA Loneliness Scales

It is important to note that these ranges do not correspond to clinically established cut-off points. Rather, they were defined based on common practices in the literature and serve to support descriptive analysis and discussion of results. As loneliness is a subjective and continuous experience, these score categories should be interpreted with caution and in context.

Figure 4.1 displays a dot plot representing the total scores on both versions of the UCLA Loneliness Scale for each participant before the intervention. Each participant is plotted along the x-axis, labeled with their identifier, age, and gender. For each participant, the green dot marks the score on the original UCLA scale, while the orange dot shows the score on the revised version. The y-axis indicates the total loneliness score, making it possible to visually compare individual results across both measurement instruments. This visualization highlights variations in loneliness perceptions depending on the scale, while also making participant-by-participant differences immediately clear. The spacing of the participants was intentionally expanded for readability and to facilitate the distinction between the two scales. To better clarify how participants were classified into low, moderate, and high loneliness categories, the detailed table originally presented as Table D.1 is also available in Appendix D for further reference.

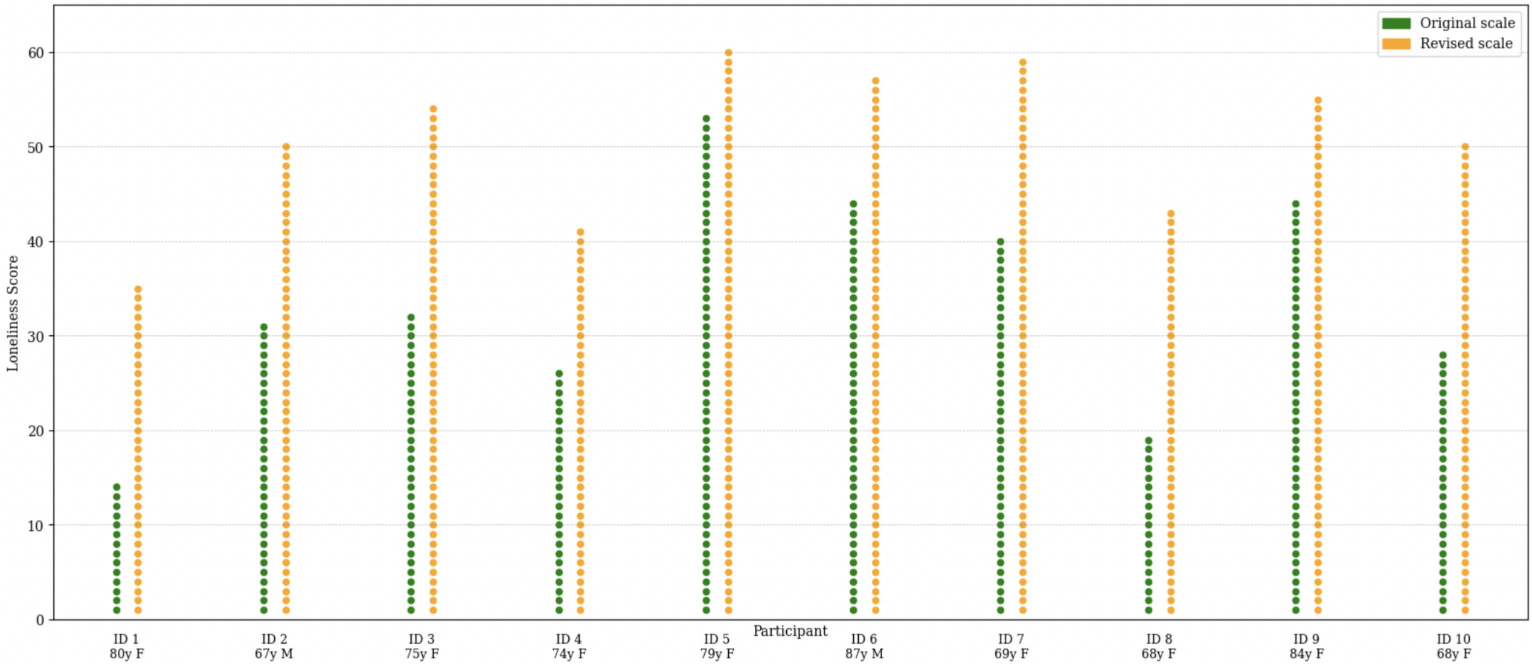

Figure 4.1: Dot plot of loneliness scores before the intervention.

Basic descriptive statistics were calculated to characterize the initial profile of participants in terms of perceived loneliness and age. As presented in Table 4.2, the group exhibited moderate average scores on both the original and revised versions of the UCLA Loneliness Scale, with observable variation in individual responses.

Variable	Mean ± SD	Min	Max
Original UCLA Score (0–60)	33.1 ± 12.1	14	53
Revised UCLA Score (20–80)	50.4 ± 8.3	35	60
Age (years)	75.1 ± 7.2	67	87

Table 4.2: Descriptive statistics for original and revised UCLA scales and participant age.

To further explore the distribution of loneliness scores, box plots were generated for both versions of the UCLA Loneliness Scale (Figures 4.2 and 4.3). These visualizations illustrate central tendency, variability, and potential outliers.

Each plot represents the interquartile range (IQR), capturing the middle 50% of the data, while the line inside the box indicates the median score. Whiskers extend to the smallest and largest values within 1.5 times the IQR. Individual dots correspond to participant scores, offering additional detail on the score distribution and possible clusters.

A comparative inspection reveals subtle differences in dispersion and symmetry between the two scales. Collectively, these plots offer a concise yet informative overview of the perceived loneliness of participants prior to the intervention.

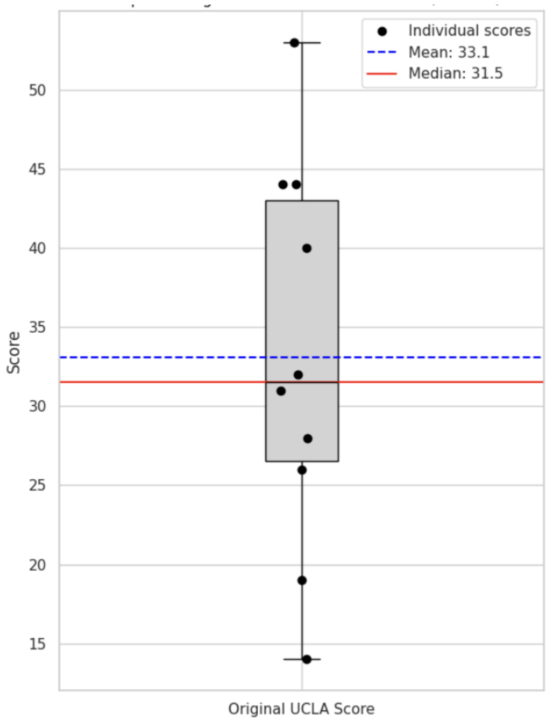

Figure 4.2: Box plot of scores on the original UCLA Loneliness Scale

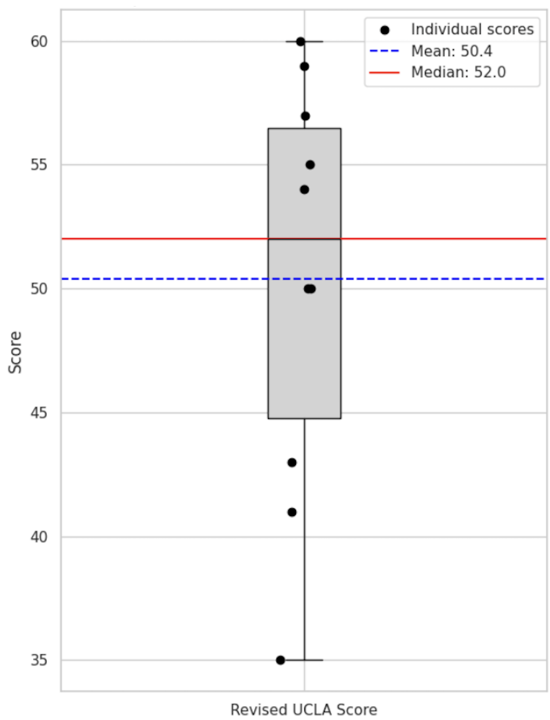

Figure 4.3: Box plot of scores on the revised UCLA Loneliness Scale

To complement the box plots, histograms were created to visualize the distribution of loneliness scores in predefined intervals (Figures 4.4 and 4.5). These histograms reveal concentration patterns and spread among participants, with vertical lines marking the mean and median values for each scale. The histogram of the original scale (0–60) shows that most of the participants scored within the moderate range, with some placed at the extremes. The revised scale (20-80) reflects a similar trend, although with slightly lower dispersion. Together, these figures enrich descriptive statistics by providing an intuitive sense of how loneliness was distributed in the group before the intervention.

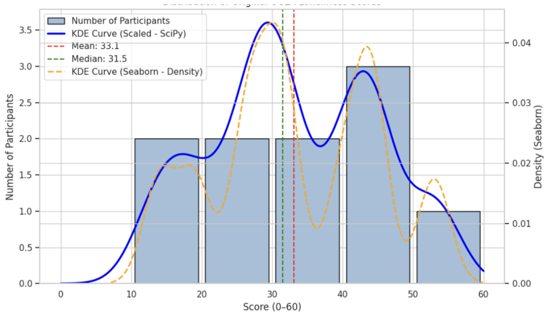

Figure 4.4: Histogram of scores on the original UCLA Loneliness Scale

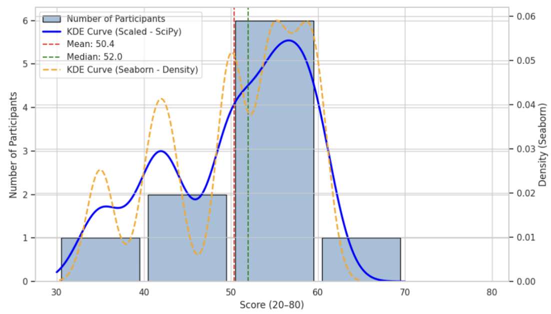

Figure 4.5: Histogram of scores on the revised UCLA Loneliness Scale

4.4 Post-intervention Quantitative Evaluation

Figure 4.6 illustrates the individual loneliness scores of each participant after completing the intervention, using the original and revised versions of the UCLA Loneliness Scale. For each participant, the green dots represent their scores on the original scale, while the orange dots indicate their scores on the revised scale. Each dot corresponds to one scale point, plotted cumulatively to convey the perceived magnitude of loneliness on both measures. The participant codes are shown on the x axis, along with their age and gender, while the y axis represents the loneliness score. Horizontal dashed lines were added at intervals of 10 points to facilitate visual reading. This visualization supports the interpretation of how loneliness levels varied between participants and between scale versions. The corresponding numerical scores and their classification into low, moderate, or high loneliness can be found in Table E.1 in Appendix E for additional reference.

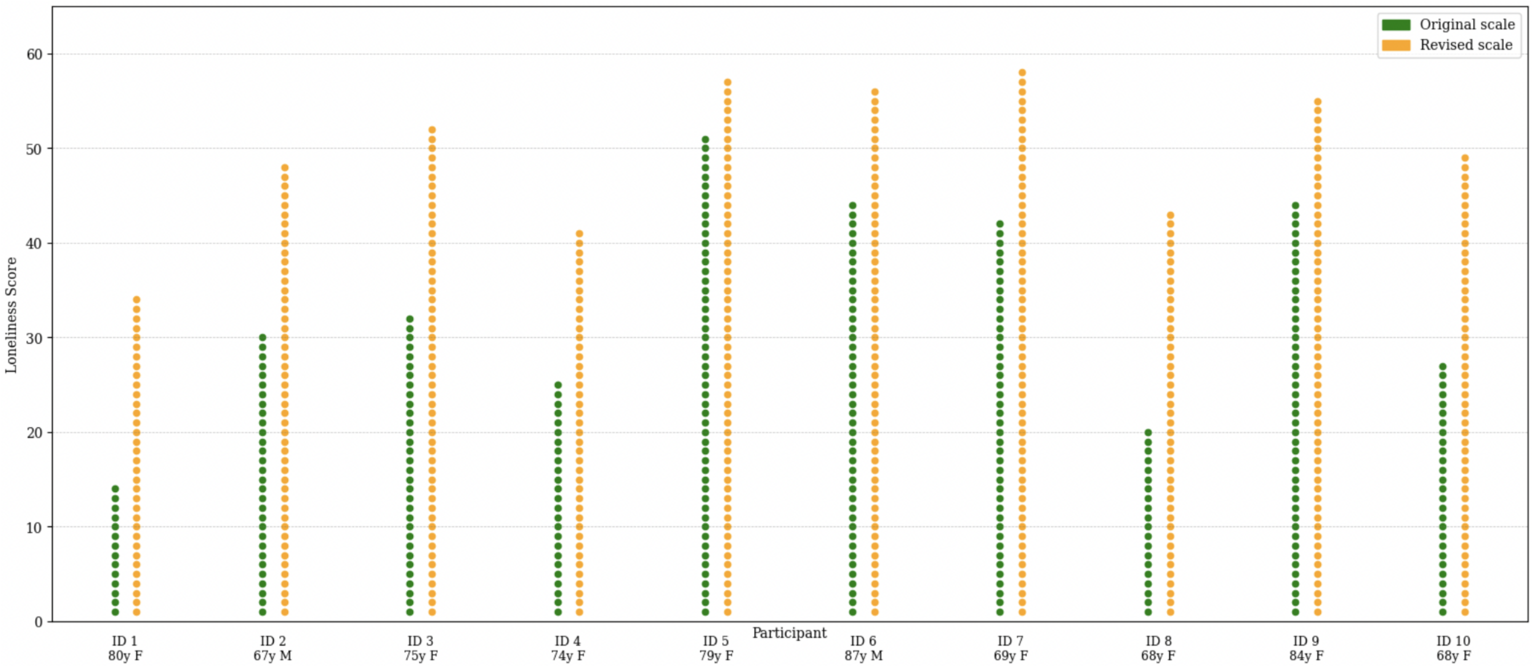

Figure 4.6: Dot plot of loneliness scores before the intervention.

Table 4.3 reports the descriptive statistics after the intervention. Both scales showed slightly lower mean scores and reduced maximum values compared to pre-session results. These modest reductions suggest an overall improvement in the perceived social well-being of the participants after the intervention.

Variable	**Mean ± SD**	**Min**	**Max**
Original UCLA Score (0–60)	32.9 ± 12.0	14	51
Revised UCLA Score (20–80)	49.3 ± 7.9	34	58

Table 4.3: Descriptive statistics for original and revised UCLA scales after the intervention

Figures 4.7 and 4.8 present post-intervention box plots for both scales. The visualizations indicate a convergence of scores around the moderate range, with fewer extreme values. The blue and red lines mark the mean and median, respectively, underscoring the central tendency and aligning with the observed reduction in perceived loneliness.

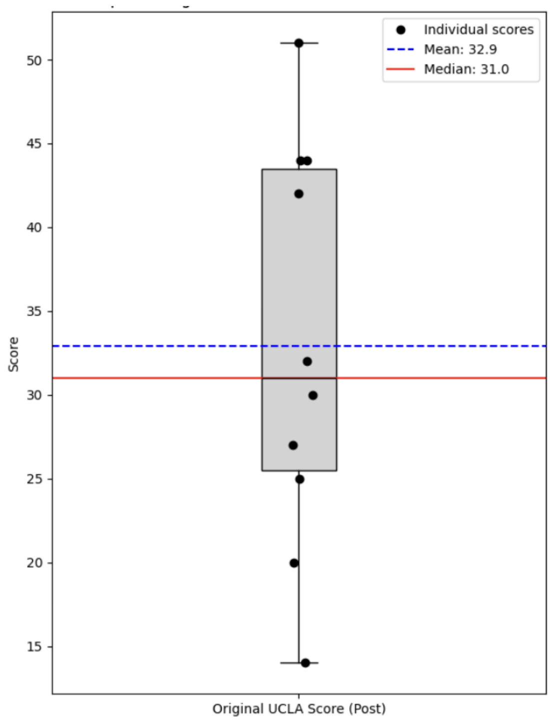

Figure 4.7: Box plot of scores on the original UCLA Loneliness Scale after the intervention

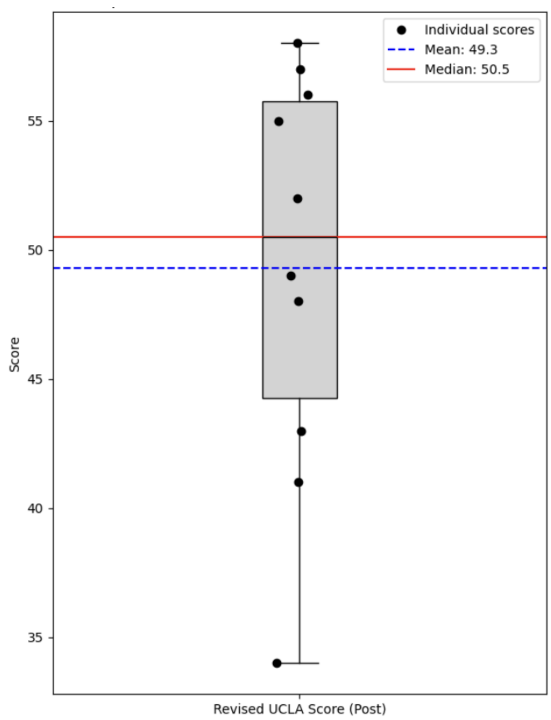

Figure 4.8: Box plot of scores on the revised UCLA Loneliness Scale after the intervention

The histograms in Figures 4.9 and 4.10 provide a visual representation of the post-session score distributions. The presence of kernel density estimation (KDE) curves offers additional insight into the shape and concentration of responses. A clear clustering around the middle ranges can be observed, with the revised scale displaying a smoother and more symmetrical distribution. These trends reinforce the conclusion of moderate improvement in the perception of loneliness after the intervention.

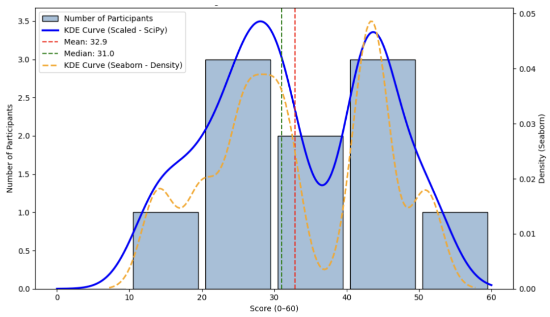

Figure 4.9: Histogram of scores on the original UCLA Loneliness Scale after the intervention

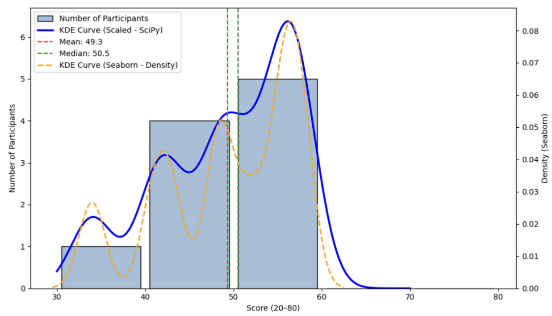

Figure 4.10: Histogram of scores on the revised UCLA Loneliness Scale after the intervention

4.5 Comparative Analysis of Quantitative Outcomes

Paired-sample t-tests were conducted to evaluate whether the intervention led to statistically significant changes in perceived loneliness of the participants. Original and revised versions of the UCLA Loneliness Scale were used, with mean scores compared before and after the intervention within the same participant group. Table 4.4 presents the results, including the mean difference, t-statistic, associated p-value, and the 95% confidence interval. Although no significant changes were found on the original scale, the revised version revealed a statistically significant reduction in loneliness after the intervention.

Scale	Mean Difference	t	p-value	95% CI
UCLA Original	-0.2	0.557	0.5911	[-0.90, 0.50]
UCLA Revised	-1.1	3.498	0.0067	[-1.72, -0.48]

Table 4.4: Paired t-test results comparing pre- and post-intervention loneliness scores

Cohen's d was calculated to determine the magnitude of the observed differences in the loneliness scores. This standardized effect size quantifies the mean difference in relation to the variability in the responses of the participants. As shown in Table 4.5, the original scale produced a negligible effect, while the revised scale showed a large negative effect, indicating a substantial reduction in perceived loneliness.

Scale	Cohen's d
UCLA Original	-0.176
UCLA Revised	-1.106

Table 4.5: Effect size (Cohen's d) for pre–post differences in loneliness scores

A clearer representation of individual changes in perceived loneliness was achieved using paired line plots for both the original and revised versions of the UCLA Loneliness Scale (Figure 4.11). Each line connects the pre- and post-intervention scores of the participant, providing a visual overview of the direction and magnitude of the change. A general downward trend is evident, especially on the revised scale, indicating a reduced loneliness after the sessions. Although every participant is represented by a line, the plot for the original scale appears to display only nine trajectories. This is due to the fact that Participants 6 and 9 have identical scores before and after the intervention (Pre: 44, Post: 44), causing their lines to overlap completely, a common occurrence in paired visualizations when the trajectories are identical.

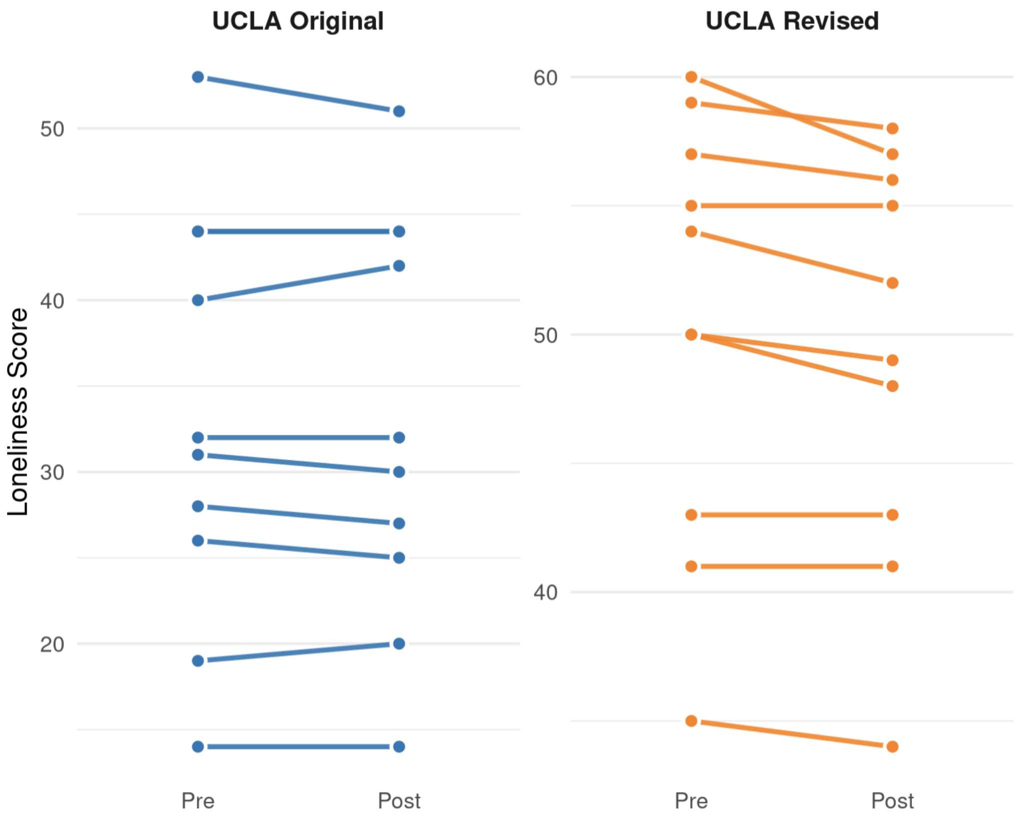

Figure 4.11: Paired pre- and post-intervention scores on both versions of the UCLA Loneliness Scale. Each line represents one participant.

In addition to individual-level visualizations, a bar chart was generated to display the mean loneliness scores before and after the intervention for both the original and revised versions of the UCLA Loneliness Scale (Figure 4.12). Each bar reflects the group average at a specific time point, with vertical error bars representing the standard error of the mean (SEM), providing an indication of score variability and statistical confidence.

The graph shows a modest reduction in mean scores across both scales after the intervention. On the original scale (0–60), the average decreased slightly from 33.1 to 32.9. On the revised scale (20–80), the drop was more pronounced, from 50.4 to 49.3. Although these changes are relatively small, they align with the downward trends observed in individual trajectories and support the results of the paired *t*-tests. The choice of SEM over standard deviation facilitates a clearer interpretation of changes at the group level, particularly in studies involving small samples.

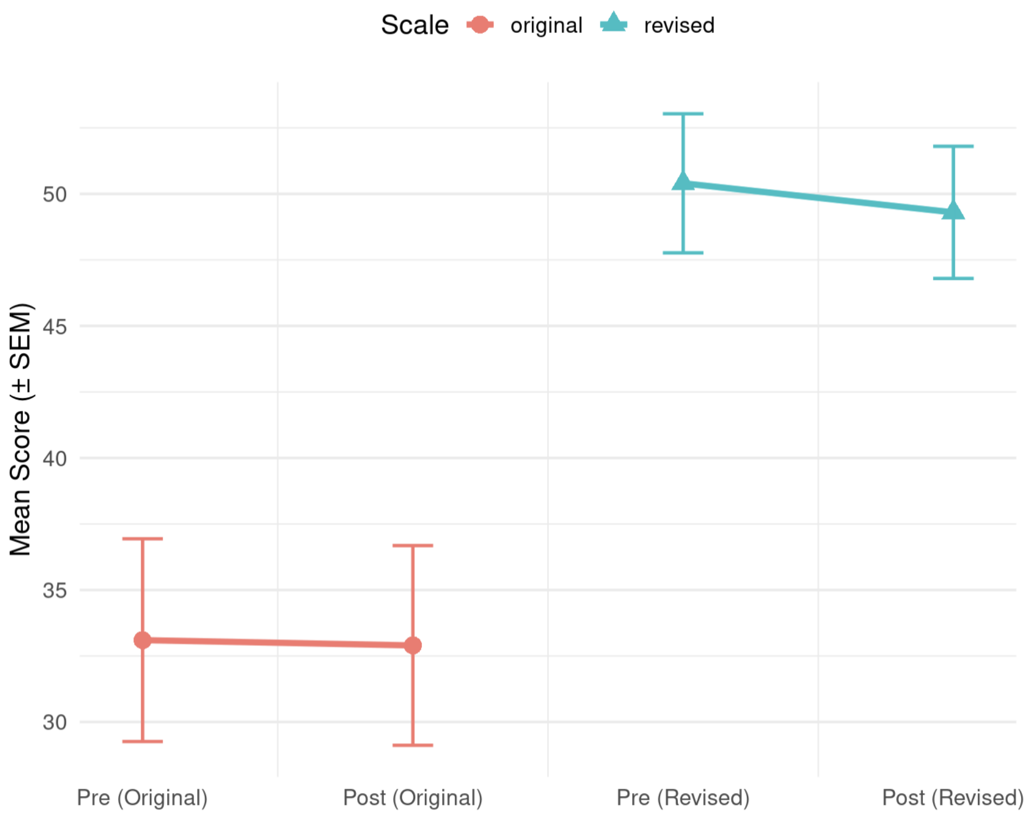

Figure 4.12: Group mean loneliness scores (± SEM) for the original and revised UCLA scales before and after the intervention.

4.6 Summary of Quantitative Results

The quantitative findings of this exploratory study suggest that the virtual moderation system may have contributed to a slight reduction in perceived loneliness among participants. Both versions of the UCLA Loneliness Scale, original and revised, showed modest but consistent decreases in mean scores after the intervention. Although the paired-sample t-tests did not reveal statistically significant differences for the original scale, the revised scale showed a significant reduction with a large effect size ($Cohen's\ d = -1.106$), indicating a potentially meaningful impact. However, given the small absolute change in mean scores, its clinical relevance and practical significance should be interpreted with caution.

The pairwise analysis of the participants, grouped as (1 and 2), (3 and 4), (5 and 6), (7 and 8), and (9 and 10), highlighted considerable variability in individual responses to the intervention. Some pairs, particularly those with higher baseline loneliness scores (e.g., participants 5 and 6), showed more notable reductions, suggesting that the intervention may be more effective for individuals experiencing greater loneliness. In contrast, participants with already low levels of loneliness tended to remain stable, which can also be interpreted positively as the maintenance of well-being.

Descriptive analyses and visualizations provided further insight into these patterns. Box plots and histograms showed a general post-intervention shift toward moderate or lower levels of loneliness, with fewer extreme scores. Paired line plots highlighted individual trajectories, revealing that most of the participants improved or remained stable in their scores. In particular, overlapping trajectories in some cases (e.g. identical pre-post scores) underscored the subtlety of change.

The bar charts summarizing the group means and standard error confirmed the overall trend, despite the modest magnitude of change. These visual representations reinforce the interpretation that the intervention had a stabilizing or slightly positive effect on emotional well-being, particularly within the short three-session time frame and small sample.

Together, these results warrant further investigation with larger, more diverse samples, and longer durations. They also underscore the value of combining statistical, visual, and pairwise analytic strategies to detect nuanced changes in subjective outcomes such as loneliness.

Chapter 5

Conclusion and Future Work

5.1 Conclusion

This dissertation contributes to the field of immersive technologies for aging populations by proposing, developing, and evaluating a novel virtual moderator for social interaction. Its key contributions include the conceptualization of a structured conversation model tailored to the communication preferences of older adults, the technical implementation of a real-time voice-based moderator powered by natural language processing and synthesized speech, the integration of the system within a Unity-based VR platform featuring facial animation and speaker indication cues, and empirical validation through a small-scale experimental study, demonstrating its impact on perceived loneliness and user satisfaction. This work addresses a clear gap in existing literature, namely the absence of structured AI-supported moderation in VR conversations, and shows that such systems can play a meaningful role in fostering social interaction and emotional well-being among seniors.

The results of this study also provide direct answers to the hypotheses, research questions, and objectives defined in Chapter 1. Regarding the hypotheses, H1 predicted that the VR-based moderator would reduce perceived loneliness among older adults. This was supported by quantitative evidence from the UCLA Loneliness Scale, which showed a consistent reduction in scores in 9 out of 10 participants, and by subjective feedback indicating emotional benefit, thus partially validating the hypothesis. H2 proposed that the moderator would support deeper and more meaningful conversations, a claim clearly supported by qualitative data: many participants, despite living in the same care facility, reported that they had rarely spoken to their assigned conversation partner before, but described forming meaningful bonds at the end of the sessions. In some cases, lasting friendships emerged, highlighting the role of the moderator in facilitating genuine interpersonal connection. These findings directly respond to the research questions: RQ1 is addressed through the observed reduction in loneliness; RQ2 is affirmed by the improved quality of interactions and perceived recognition; RQ3 is supported by the overall positive user experience, despite some usability challenges. The voice of the system, visual cues and personalized memory were key characteristics that improved social presence. All four research objectives were also met. The system was designed according to the communicative needs and preferences of older adults (O1); its impact on perceived loneliness was evaluated through pre- and post-intervention assessments using both the original and revised versions of the UCLA Loneliness Scale (O2). Qualitative data from interviews and session observations supported the potential of the virtual moderator to foster more structured and meaningful conversations (O3). Finally, participants' feedback highlighted emotional and social benefits while also identifying areas for technical improvement (O4). Collectively, these results reinforce the alignment between the initial objectives of the dissertation and its final contributions, confirming that the proposed system fulfills its intended role as a structured and supportive social technology for older adults.

Although the study demonstrated encouraging results, several limitations must be acknowledged. The limited number of participants ($n = 10$) restricts the generalizability of the findings. In particular, the sample was unbalanced in terms of gender, with only two male participants, which limited the ability to explore potential differences in response between genders. Although the results revealed promising trends, such as a statistically significant reduction in perceived loneliness on the revised UCLA scale, the small sample size limits statistical power and increases susceptibility to outliers. Furthermore, the absence of a control group prevents causal attribution, which means that improvements in loneliness scores, while aligned with the intervention, cannot be definitively attributed to it. However, it is difficult to dismiss the fact that several participants showed marked improvements, which makes it plausible that the intervention played a meaningful role in shaping the observed outcomes. However, the inclusion of paired statistical tests, individual-level visualizations, and effect size analysis represents a strong methodological effort for an exploratory study, providing a detailed picture of change patterns and supporting the interpretive value of the results.

The intervention consisted of only three 30-minute sessions, which limits the scope to observe more durable psychological changes. It is hypothesized that a longer intervention, with more frequent sessions extended over several months, could generate more consistent and sustained improvements.

From a technical perspective, the implementation phase demonstrated both robustness and innovation. The modular client-server architecture, the use of natural language processing with conversational memory, real-time voice synchronization with lip animation, and the integration of a visual indicator system reflect a high level of technical coherence and adaptability. The ability to dynamically personalize dialogue based on a user profile stored in JSON format, in combination with real-time silence detection and GPT-4-based prompt generation, contributes to a fluid and context-aware moderation system. These features offer an important strength: the balance between generative flexibility and behavioral constraints ensures relevance and empathy in responses while avoiding uncontrolled or socially inappropriate outputs.

However, this implementation also faces practical challenges. The non-immersive VR format, while chosen for practicality, may have limited the degree of sensory presence and engagement compared to fully immersive alternatives. Furthermore, certain aspects of real-time system performance were occasionally identified as suboptimal. Participants reported delays in moderator responses and noted slight repetition in phrasing, which can be attributed to latency in the processing pipeline and limitations of generative AI under tight interaction constraints. Moreover, the use of third-party services (Google STT, Azure TTS, GPT-4) introduces not only potential long-term sustainability issues (given the reliance on external APIs) but also possible concerns regarding latency, data handling, and privacy, despite the protective measures implemented.

In general, both the implementation and evaluation phases reveal a thoughtful and comprehensive approach. The system performs consistently across platforms, handles real-time communication effectively, and integrates AI technologies in a way that respects the emotional needs of the user group. However, the transition from prototype to deployment in real-world care settings will require broader testing, simplification of the system to allow greater ease of use, and greater autonomy in operation.

The VR-based intervention showed potential to foster moments of social connection and well-being; however, it should be emphasized that this system is not intended to replace real human interaction. Rather, it should be understood as a complementary alternative, particularly useful in contexts of limited mobility or social isolation. However, its constant or prolonged use is not recommended, as it can promote digital dependency or reduce motivation for in-person contact. Therefore, this tool should be implemented in a balanced way, ideally combined with real-life social activities and human support, with critical awareness of its limitations.

5.2 Future Work

The findings of this exploratory study suggest several promising directions for future work, both in terms of methodological expansion and technical evolution. Although some participants showed improvement, longitudinal studies are needed to assess whether these gains are sustained over time, how the system affects motivation and engagement in the long term, and whether the novelty effect plays a significant role. Implementing extended interventions over several weeks or months would allow a more robust evaluation of emotional and behavioral changes. Furthermore, a comparison with alternative conditions, such as sessions without a moderator, with human facilitation, or with traditional chatbots, would help isolate the specific contributions of the AI-based system and improve causal inference.

From a methodological point of view, the analysis did not explore potential moderating variables such as age, sex, or prior technological experience. Future studies would benefit from testing statistical correlations between loneliness scores and demographic or psychosocial variables. In particular, it would be relevant to examine the differences between male and female participants and how various age groups perceive and benefit from the intervention. These analyses could reveal subpopulation-specific patterns and allow for more targeted design strategies. Furthermore, employing more robust statistical techniques, such as parametric tests and linear regression, in studies with larger and more balanced samples would strengthen the evidential value and allow generalization of the results.

Regarding personalization, future systems could integrate adaptive learning mechanisms that adjust dialogue prompts based on real-time sentiment analysis, emotional states, or individual history. The inclusion of multimodal recognition of affect (e.g., voice tone, facial expression) could enhance responsiveness and empathy. The ability to dynamically adapt vocabulary, pacing, or conversation themes to suit the cognitive profile, emotional needs, and preferences of each user would further improve the depth and authenticity of the experience. Participants' suggestions for incorporating occasional humor and emotional nuance should be explored, as they can contribute to greater trust and engagement.

In terms of context, future implementations should occur in real-world institutional environments such as nursing homes, day centers, or aging-in-place programs, where the system can be integrated into regular routines and assessed for broader social impact. Integrating the moderator into telehealth or psychological support programs could also offer expanded opportunities for engagement. In addition, expanding language capabilities to include speakers of other languages would enhance the system's applicability across diverse populations.

To improve usability and interaction, it is important to test the system with diverse users. This includes evaluating how older adults with limited experience adapt to the system and how its interface and feedback mechanisms can be improved to reduce friction. A more immersive version of the system that uses head-mounted displays could also be considered for tech-savvy users, offering increased presence and embodiment. Visual elements such as avatars should be further refined to explore their impact on empathy, anthropomorphism, and user comfort.

From a scientific transparency and reproducibility perspective, future research should adopt standardized and validated measurement instruments, including additional scales such as the WHO-5 Well-being Index or the Social Self-Efficacy Scale, alongside the UCLA Loneliness Scale. Detailed documentation of all technical and procedural aspects is essential to facilitate independent replication and collaborative development of similar systems.

Finally, while the system shows promise in fostering connection and emotional well-being, it is important to reinforce that it is not intended to replace human contact or professional therapy. Rather, it should be seen as a supportive tool to complement existing social interactions, one that can reduce perceived loneliness in specific contexts but must be used with caution to avoid excessive dependence or digital attachment. Future work should explore the ethical dimensions of such interventions and define clear boundaries for their safe and effective use.

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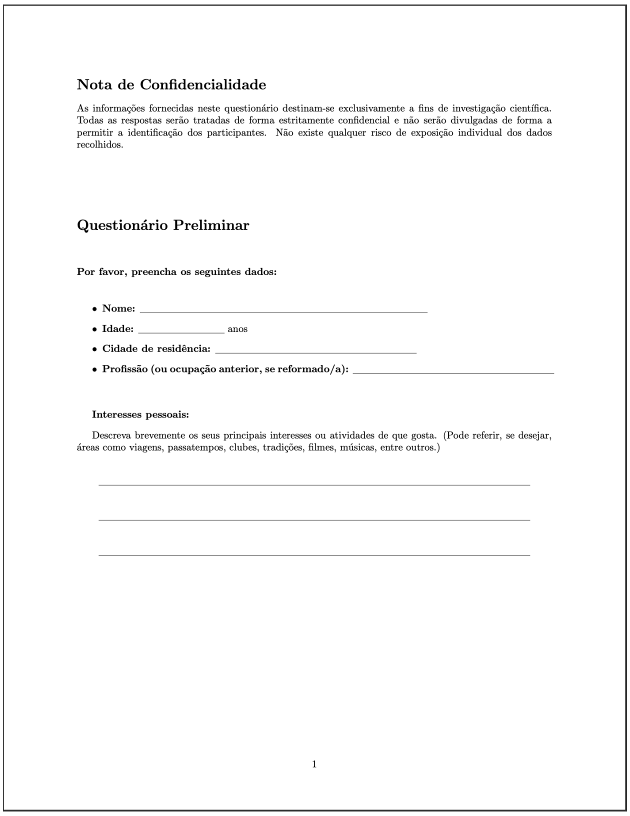
Appendix A

Personal Information and Loneliness Scales

The following images present the original versions of the questionnaires used for the quantitative assessment in this study. These were administered in Portuguese, as presented to the participants, and include the personal information form as well as the original and revised versions of the UCLA Loneliness Scale.



Nota de Confidencialidade

As informações fornecidas neste questionário destinam-se exclusivamente a fins de investigação científica. Todas as respostas serão tratadas de forma estritamente confidencial e não serão divulgadas de forma a permitir a identificação dos participantes. Não existe qualquer risco de exposição individual dos dados recolhidos.

Questionário Preliminar

Por favor, preencha os seguintes dados:

- **Nome:** ______________________
- **Idade:** __________ anos
- **Cidade de residência:** ______________________
- **Profissão (ou ocupação anterior, se reformado/a):** ______________________

Interesses pessoais:

Descreva brevemente os seus principais interesses ou atividades de que gosta. (Pode referir, se desejar, áreas como viagens, passatempos, clubes, tradições, filmes, músicas, entre outros.)

____

____

____

1

Figure A.1: Page 1 of the questionnaire administered to participants.

Questionário 2 (UCLA Loneliness Scale)

Instruções:
3 indica “Sinto-me frequentemente assim”
2 indica “Sinto-me às vezes assim”
1 indica “Sinto-me raramente assim”
0 indica “Nunca me sinto assim”

Use uma apenas uma cruz em cada bloco horizontal.

Afirmação	**3**	**2**	**1**	**0**
1. Estou infeliz por fazer tantas coisas sozinho(a)				
2. Não tenho ninguém com quem conversar				
3. Não consigo suportar estar tão sozinho(a)				
4. Falta-me companhia				
5. Sinto que ninguém me compreende verdadeiramente				
6. Dou por mim à espera que alguém me telefone ou escreva				
7. Não há ninguém a quem possa recorrer				
8. Já não estou próximo(a) de ninguém				
9. Os meus interesses e ideias não são partilhados por quem me rodeia				
10. Sinto-me excluído(a)				
11. Sinto-me completamente sozinho(a)				
12. Sou incapaz de comunicar com as pessoas à minha volta				
13. As minhas relações sociais são superficiais				
14. Sinto-me carente de companhia				
15. Ninguém me conhece realmente bem				
16. Sinto-me isolado(a) dos outros				
17. Estou infeliz por estar tão retraído(a)				
18. É difícil para mim fazer amigos(as)				
19. Sinto-me rejeitado(a) e excluído(a) pelos outros				
20. As pessoas estão à minha volta, mas não estão comigo				

2

Figure A.2: Page 2 of the questionnaire administered to participants.

Questionário 3 (Revised UCLA Loneliness Scale)

Instruções: Indique com uma cruz, com que frequência cada uma das afirmações abaixo o(a) descreve:
4 = Frequentemente   3 = Às vezes   2 = Raramente   1 = Nunca

Use uma apenas uma cruz em cada bloco horizontal.

Afirmação	**4**	**3**	**2**	**1**
1. Sinto-me em sintonia com as pessoas à minha volta				
2. Sinto falta de companhia				
3. Não tenho ninguém a quem recorrer				
4. Não me sinto sozinho(a)				
5. Sinto-me parte de um grupo de amigos				
6. Tenho muito em comum com as pessoas à minha volta				
7. Já não estou próximo(a) de ninguém				
8. Os meus interesses e ideias não são partilhados pelas pessoas à minha volta				
9. Sou uma pessoa extrovertida				
10. Existem pessoas de quem me sinto próximo(a)				
11. Sinto-me excluído(a)				
12. As minhas relações sociais são superficiais				
13. Ninguém me conhece realmente bem				
14. Sinto-me isolado(a) dos outros				
15. Consigo encontrar companhia quando quero				
16. Existem pessoas que realmente me compreendem				
17. Estou infeliz por estar tão retraído(a)				
18. As pessoas estão à minha volta mas não comigo				
19. Existem pessoas com quem posso conversar				
20. Existem pessoas a quem posso recorrer				

3

Figure A.3: Page 3 of the questionnaire administered to participants.

Personal Information and Loneliness Scales

Appendix B

Qualitative Feedback Questionnaire

The following form was used to collect qualitative feedback from participants after completing the three moderated sessions in the virtual environment. The questions were designed to capture the participants' perceptions of the experience.

Questionário sobre a Experiência com o Moderador Virtual

Nome do participante: ____________________

1. Foi fácil conversar com outra pessoa nesta experiência?

( ) Sim ( ) Não

2. Sentiu que o moderador ajudou a conversa?

( ) Sim ( ) Não

3. O moderador pareceu-lhe alguém real?

( ) Sim ( ) Não

4. Sentiu-se à vontade para falar e ser ouvido(a)?

( ) Sim ( ) Não

5. Teve alguma dificuldade ao usar o sistema?

( ) Sim ( ) Não

6. Gostou da experiência?

( ) Sim ( ) Não

7. Gostaria de repetir esta experiência no futuro?

( ) Sim ( ) Não

8. Considera que esta experiência teve um impacto positivo na sua vida?

( ) Sim ( ) Não

9. Voltaria a usar este sistema com familiares ou amigos?

( ) Sim ( ) Não

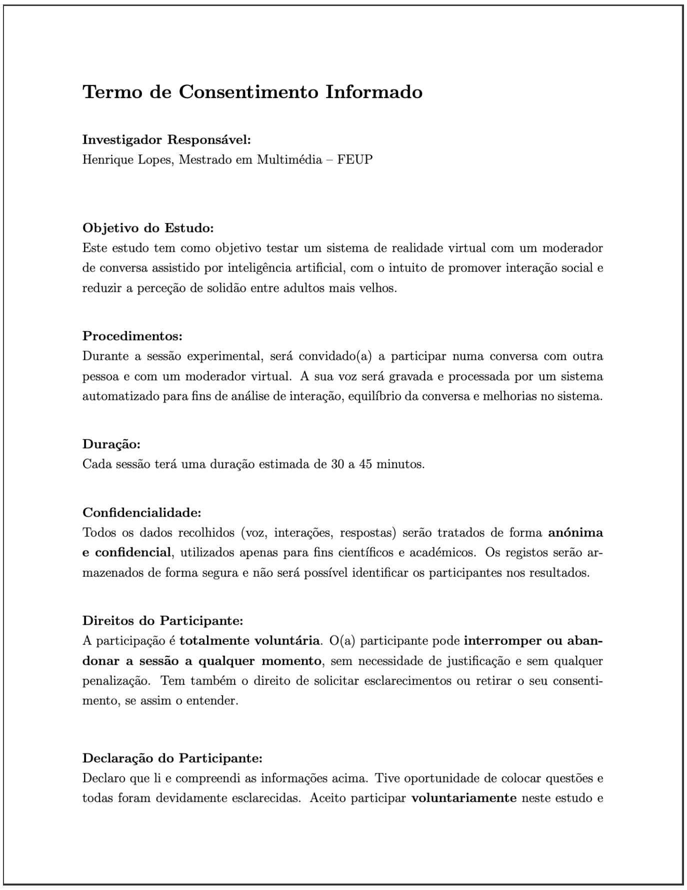
Figure B.1: Qualitative evaluation form used after the completion of the moderated sessions.

Qualitative Feedback Questionnaire

Appendix C

Informed Consent Form

Before participating in the study, all users received an informed consent form explaining the objectives of the research, how their data would be used, and their rights regarding participation and withdrawal. The form emphasized the voluntary nature of participation, the confidentiality of any data collected, and compliance with ethical and data protection regulations. Participants were given the opportunity to ask questions and were only included in the study after signing the document.



Termo de Consentimento Informado

Investigador Responsável:
Henrique Lopes, Mestrado em Multimédia – FEUP

Objetivo do Estudo:
Este estudo tem como objetivo testar um sistema de realidade virtual com um moderador de conversa assistido por inteligência artificial, com o intuito de promover interação social e reduzir a perceção de solidão entre adultos mais velhos.

Procedimentos:
Durante a sessão experimental, será convidado(a) a participar numa conversa com outra pessoa e com um moderador virtual. A sua voz será gravada e processada por um sistema automatizado para fins de análise de interação, equilíbrio da conversa e melhorias no sistema.

Duração:
Cada sessão terá uma duração estimada de 30 a 45 minutos.

Confidencialidade:
Todos os dados recolhidos (voz, interações, respostas) serão tratados de forma **anónima e confidencial**, utilizados apenas para fins científicos e académicos. Os registos serão armazenados de forma segura e não será possível identificar os participantes nos resultados.

Direitos do Participante:
A participação é **totalmente voluntária**. O(a) participante pode **interromper ou abandonar a sessão a qualquer momento**, sem necessidade de justificação e sem qualquer penalização. Tem também o direito de solicitar esclarecimentos ou retirar o seu consentimento, se assim o entender.

Declaração do Participante:
Declaro que li e compreendi as informações acima. Tive oportunidade de colocar questões e todas foram devidamente esclarecidas. Aceito participar **voluntariamente** neste estudo e

Figure C.1: First page of Informed consent form compreendo que posso desistir da participação **a qualquer momento**, sem prejuízo.

Assinatura: ______________________________

Data: __________ (Dia) / __________ (Mês) / __________ (Ano)

Figure C.2: Second page of Informed consent form

Appendix D

Table of Loneliness Scores Before the Intervention

This table summarizes the loneliness scores of participants prior to intervention, including their age and qualitative classification (low, moderate, or high). In general, most of the participants were classified as moderately lonely on both the original and revised scales, with only a few showing high or low loneliness. These baseline results provided a reference point for evaluating the impact of the virtual moderation system.

Participant	Original Score	Level (Original)	Revised Score	Level (Revised)	Age	Gender
1	14	Low	35	Low	80	Female
2	31	Moderate	50	Moderate	67	Male
3	32	Moderate	54	Moderate	75	Female
4	26	Moderate	41	Moderate	74	Female
5	53	High	60	High	79	Female
6	44	High	57	Moderate	87	Male
7	40	High	59	Moderate	69	Female
8	19	Low	43	Moderate	68	Female
9	44	High	55	Moderate	84	Female
10	28	Moderate	50	Moderate	68	Female

Table D.1: Scores on loneliness before sessions

Table of Loneliness Scores Before the Intervention

Appendix E

Table of Loneliness Scores After the Intervention

The post-intervention results indicate a modest reduction in perceived loneliness among participants following the three-session program. Both the mean and maximum scores on the original and revised versions of the UCLA Loneliness Scale showed decreases, suggesting a positive trend in social well-being. Although two individuals reported a slight increase of one point, the overall pattern points toward an improvement in perceived loneliness, consistent with the intended supporting role of the virtual moderation system.

Participant	Original Score	Level (Original)	Revised Score	Level (Revised)
1	14	Low	34	Low
2	30	Moderate	48	Moderate
3	32	Moderate	52	Moderate
4	25	Moderate	41	Moderate
5	51	High	57	Moderate
6	44	High	56	Moderate
7	42	High	58	Moderate
8	20	Moderate	43	Moderate
9	44	High	55	Moderate
10	27	Moderate	49	Moderate

Table E.1: Scores on loneliness after sessions