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ORIGINAL ARTICLE

Acceptability and feasibility of virtual reality multisensory environments for individuals with neurodevelopmental disorders: professional caregiver perspectives

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Abstract
This study investigates the acceptability and feasibility of Virtual Reality Multisensory Environments (VR MSEs) to support sensory exploration among individuals with neurodevelopmental disorders (NDD). To assess user acceptance of VR MSEs, data were collected from 40 professional caregivers, including occupational therapists, special education teachers, and administrative staff who are involved in the care of individuals with NDD. Quantitative and qualitative approaches were employed, incorporating the Technology Acceptance Model (TAM), Personal Wellbeing Index-Intellectual Disability 3rd Edition (PWA-ID), and semi-structured interviews. The findings revealed significant ($p<0.05$) acceptance of VR MSEs, and professional caregivers anticipated positive impacts on the well-being of individuals with NDD. Thematic analysis identified five themes relevant to feasibility: sensory customization, sensory simulation quality, intuitive interface design, use of VR device, and user characteristics. This study highlights the potential of VR MSEs as a scalable alternative to traditional multisensory environments, addressing spatial and financial barriers while supporting diverse sensory needs. Continuous professional caregiver involvement and iterative design processes will be crucial in optimizing usability and successful implementation.

Keywords Virtual reality · Multisensory environment · Technology acceptance model · Neurodevelopmental disorders

1 Introduction

Sensory processing patterns differ among individuals. Environments are not always accommodating such differences, resulting in some individuals experiencing over- or under-sensitivity to sensory inputs, called sensory over-responsivity (SOR) or sensory under-responsivity (SUR), respectively (Ayres 1972; Miller et al. 2007). For example, certain environmental factors, such as background noise or intense light, can overwhelm the senses, resulting in a sense of fatigue, difficulty concentrating, and maintaining focus. These feelings are typically temporary; however, SOR or SUR is problematic when it negatively affects daily functioning, self-regulation, and social interaction in the long term. SOR or SUR may externally manifest in behaviors such as stimming (e.g., repetitive, self-stimulating, self-soothing movements or sounds) and aggression in some cases. While these responses are natural coping mechanisms to SOR or SUR, these behaviors may prevent the population from fully participating in home, school, and community activities, ultimately affecting their quality of life (Chaturvedi et al. 2025; Yi and Ellis 2023; Ellis and Yi 2023; Ben-Sasson et al. 2009; Cuvo et al. 2001).

Sensory over-responsivity (SOR) or sensory under-responsivity (SUR) are notably prevalent among children with NDD (Ben-Sasson et al. 2009; Green et al. 2016; Straub et al. 2022). Neurodevelopmental disorders under the Diagnostic and Statistical Manual of Mental Disorders,

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Fifth Edition (DSM-5) include intellectual disorders (ID) (e.g., intellectual developmental disorder, developmental delay, unspecified intellectual disability), communication disorders, autism spectrum disorder (ASD), attention-deficit/hyperactivity disorder (ADHD), specific learning disorders (LD), and others (American Psychiatric Association 2013). This population is important since the report from the National Institute of Health (NIH) estimates the prevalence of neurodevelopmental disorders as 8.5%, 2.9%, 1.4%, and 6.4% for ADHD, ASD, ID, and LD, respectively (Yang et al. 2022).

1.1 Multisensory environments

To accommodate the multifaceted needs of individuals with SOR or SUR, the body of knowledge on sensory integration was initially developed by Ayres Sensory Integration® (Ayres 1972). Sensory integration theory (SIT) focuses on how sensory information is perceived, processed, and responded to by the brain and body. SIT also identifies supportive environments based on clinical observations (Roley et al. 2007). A multisensory environment (MSE), also called Snoezelen room, is a particularly supportive environment for individuals with sensory processing differences (Yi and Heidari Matin 2025). MSE provides a variety of sensory experiences through sight, hearing, touch, smell, taste, body position, and body awareness. MSEs in a physical world are often designed with sensory equipment that can either stimulate or calm different sensory modalities, such as interactive lighting, adjustable sound system, diverse tactile surfaces, etc. MSEs can be operated by individual's self-directed exploration or by trained therapists' clinical guidance. For example, individuals who experience SOR or SUR can adjust sensory equipment according to their interests and preferences. In therapeutic setting, MSE can be operated by therapist based on patients' therapeutic needs (Parham et al. 2008). In this way, MSEs support different sensory exploration for those with varying sensory needs.

Due to the reported benefit of MSEs on behavioral changes and psychological well-being, the demands for MSEs include educational, healthcare, leisure, and residential settings to assist people with diverse sensory needs. However, the use of physical MSEs is limited in various settings because they require significant space to accommodate specialized equipment. Furthermore, there is a financial burden to purchase special equipment. These space requirements and high costs have been a barrier to the wider applications (Cameron et al. 2020; Grace 2020).

1.2 Virtual reality technology

Virtual Reality (VR) holds the potential to lower such barriers faced by traditional MSEs. VR simulates attributes of real-world environments while addressing spatial challenges inherent in physical environments. Furthermore, the rapid advancement of VR technology has made it more affordable and accessible (Beheiry et al. 2019), enabling VR to provide sensory experiences without the spatial and financial constraints of traditional MSEs.

1.2.1 Virtual reality applications for NDD

VR technology has potential to support positive behaviors among individuals with NDD (Yi 2023; Yi et al. 2024). For example, Brooks et al. (2002) found that VR interventions enhance independent living skills, allowing individuals to perform daily tasks effectively. Rizzo et al. (2000) noted improvements in cognitive skills, such as attention and memory, through VR-based training programs. Additionally, Rose et al. (2002) revealed that VR can help develop spatial skills, essential for navigation and interaction with physical spaces. Collectively, these studies suggest that VR can serve as a transformative tool for skill development, autonomy and participation in daily activities for individuals with NDD.

The use of VR technology has been shown to positively impact social and psychological well-being of individuals with NDD. Ke and Lee (2016) demonstrated that VR-based collaborative activities significantly improved social interaction and communication skills in children with autism spectrum disorder (ASD). Parsons and Mitchell (2002) highlighted how VR environments provide safe settings for social skills training, leading to improved social behaviors in individuals with ASD. Furthermore, Bryant et al. (2020) found that VR technologies can enhance psychological well-being by addressing communication challenges.

Previous studies have not only addressed the benefits of VR applications, but also concerns regarding feasibility of VR for individuals with NDD. Cybersickness, a form of motion sickness, can arise when there is a conflict between the visual perception of movement in the virtual environment and the lack of corresponding physical movement by the body (Ramaseri Chandra et al. 2022). Symptoms such as nausea, dizziness, headaches, and disorientation can significantly impact the user experience. Additionally, individuals with NDD may exhibit heightened sensory sensitivities, making the physical sensation of wearing VR hardware challenging. Factors such as the weight of the headset, tightness of straps, pressure around the eyes, foreheads, or nose, and the tactile properties of materials (e.g., rubber or plastic against skin), may cause discomfort or tactile sensory overload. The types and placement of headphones, whether over-, on-, or in-ear, can further affect auditory tolerance for those with auditory SOR or SUR. Beyond sensory factors, prior studies have also addressed hardware-related constraints such as limited haptic feedback capabilities, potential connectivity issues, need for regular software updates and maintenance, and cost considerations when considering high-quality VR systems such as VR CAVE (Odell and Dorbala 2024; Kudry and Cohen 2022; Ramaseri Chandra et al. 2022; Shull and Damian 2015). Addressing these concerns is crucial to implementing VR safely and effectively, and to promote a positive user experience.

1.2.2 Use of virtual reality multisensory environments for individuals with NDD

While there has been substantial research on the application of VR for individuals with NDD, few studies have focused on VR MSE and their feasibility and effectiveness for this population. Mills et al. (2023a, b) investigated a VR sensory room for adults with disabilities, highlighting the potential benefits. However, a comprehensive understanding of VR MSEs, including their design considerations and their specific impacts on individuals with NDD, remains underexplored.

Previous studies highlighted the necessity of continuously involving professional caregivers in the design and evaluation of VR technology for individuals with NDD (Mills et al. 2023a, b). By incorporating feedback from these professional caregivers, VR environments can be tailored to meet specific needs of users, enhancing their effectiveness and safety.

1.3 Virtual reality multisensory environments (VR MSE) prototype

The VR MSE prototype was developed using Rhino and Unreal Engine, replicating existing physical MSE (Fig. 1). The VR MSE simulates visual stimuli using sensory equipment such as fiber optics, bubble tubes, color switches, projectors, etc. Auditory stimuli are delivered through over-ear headphones on the VR headset, with options of natural soundscape (e.g., bird, running water) and instrumental music with calming or upbeat qualities. Users can adjust volume levels to accommodate their individual sensory preferences. Tactile stimuli are supplementally offered through haptic feedback via vibrating hand controllers. All the equipment can be activated by participants or with remote guidance of trained support staff using a Bluetooth keyboard.

As for VR device, this study used MetaQuest Pro in response to recommendations from previous research to use wireless, portable device (Mills et al. 2023b). The Meta Quest Pro is a standalone VR headset featuring a horizontal field of view of approximately 106 degrees, a resolution of 1800×1920 pixels per eye, refresh rate of 90 Hz. It is equipped with Pancake lenses for enhanced visual clarity and weighs approximately 722 g. The headset integrates spatial audio through built-in over-ear directional speakers. This open-ear audio system minimizes direct contact and pressure on the ears, making it beneficial for users with auditory or tactile sensitivities. The headset is compatible with two Touch Pro Controllers, which incorporate haptic feedback and self-tracking capabilities. These controllers support six degrees of freedom (DoF) inside-out tracking using three embedded tracking cameras (Meta Quest Pro 2025).

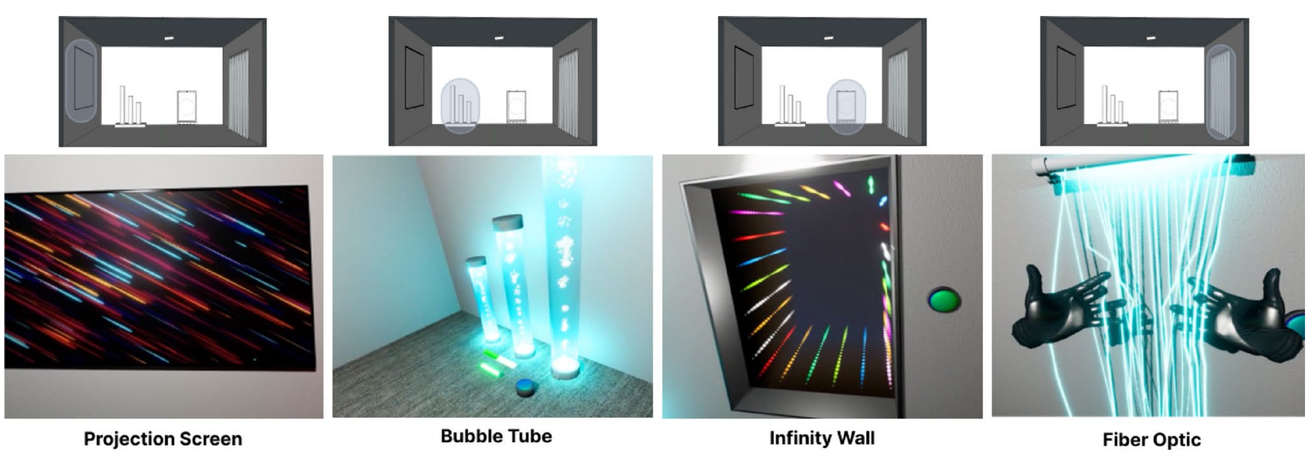


Fig. 1 VR MSE prototype

1.4 Technology acceptance model (TAM)

The Technology Acceptance Model (TAM) is a widely used framework for understanding user acceptance of new technologies. TAM examines four primary factors, including.

- Perceived usefulness (PU) refers to "the degree to which a person believes that using a particular system would enhance [their] performance" (Davis 1989, p.320),
- Perceived ease of use (PEU) reflects "the degree to which a person believes that using a particular system would be free of effort" (Davis 1989, p.320),
- Attitude to use (AU) represents an individual's positive or negative feelings toward using the technology (Al Kurdi et al. 2020), and
- Intention to use (IU) is the likelihood that an individual will adopt and continue using the system (Al Kurdi et al. 2020).

TAM posits that PU and PEU influence an individual's intention and attitude to adopt and use a technology (Davis 1989). TAM has evolved into more complex models and has been extensively tested for its validity and reliability (Napitupulu et al. 2017). TAM has been also applied across various technology domains, including virtual reality (VR), mobile applications, and e-learning platforms (Marangunić and Granić, 2015). Given its broad applicability, TAM remains one of effective models for analyzing technology adoption and user acceptance of emerging technologies.

1.5 Purpose

The purpose of this study was to assess the professional caregiver's perspective of the acceptability and feasibility of a VR MSE for individuals with NDD. Specifically, Aim 1 focused on examining the acceptability, while Aims 2 and 3 assessed the feasibility of the VR MSE. This study's aims were as follows.

Aim 1: Analyze factors influencing professional caregiver's acceptability and adoption of VR MSE, using the Technology Acceptance Model (TAM) (Figure 2).

- H1: Perceived ease of use (PEU) has a significant effect on the perceived usefulness (PU).
- H2: Perceived ease of use (PEU) has a significant effect on attitude to use (AU).
- H3: Perceived usefulness (PU) has a significant effect on attitude to use (AU).
- H4: Perceived usefulness (PU) has a significant effect on intention to use (IU).
- H5: Attitude to use (AU) has a significant effect on intention to use (IU).

Aim 2: Examine the professional caregivers' perception of the impact of VR MSE on the perceived well-being of individuals with NDD.

Aim 3: Explore design strategies of VR MSE for individuals with NDD.

2 Methods

This study employed a mixed methods approach, incorporating both quantitative and qualitative surveys. A quantitative survey was used to assess professional caregiver acceptability of VR MSEs. Semi-structured interviews were used to gather professional caregivers' in-depth insights into feasibility of VR MSEs.

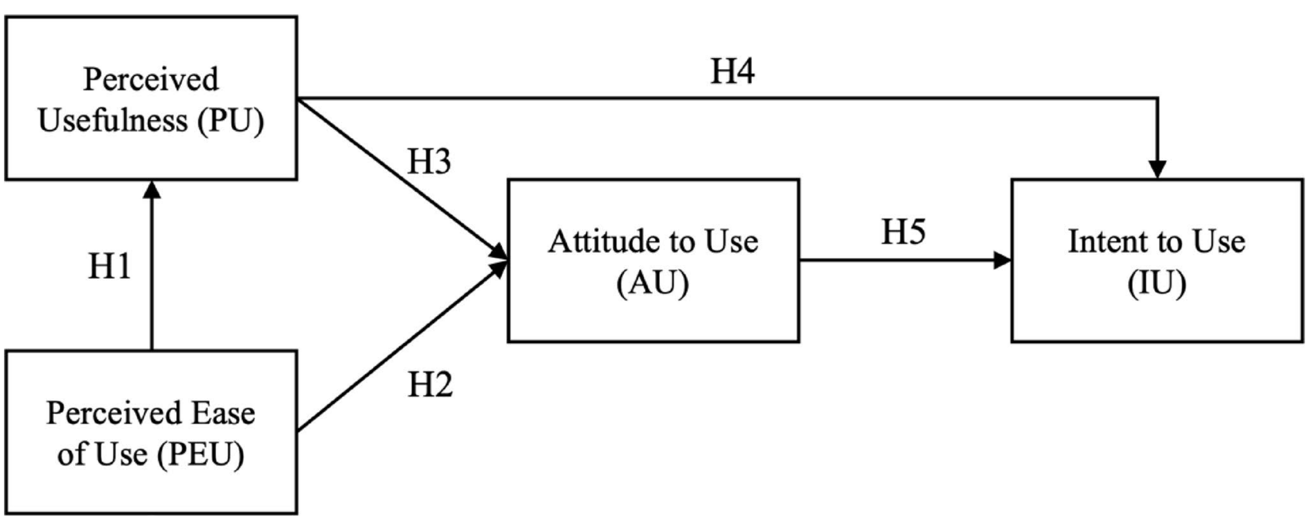


Fig. 2 Technology acceptance model tested by structural regression. *Note*. Adapted from Davis (1989)

Table 1 Participants (n=40): quantitative survey

Role	N	Work experience	
		Mean (years)	SD (years)
Occupational therapist	17	7.63	4.58
Special education teacher	4	16.52	16.49
Administrative staff*	7	5.12	2.71
Others**	12	10.27	12.09
Total	40	8.94	9.21

*Administrative staff refers to professionals responsible for program coordination and other non-clinical support roles related services for individuals with NDD

**The "Others" category includes professionals such as applied behavior analysists, special education faculty and graduate students

Table 2 Participants (n=16): qualitative interview

Group	Role	N	Work experience	
			Mean (years)	SD (years)
Focus group 1 (n=6)	Occupational Therapist	4	9	0.82
	Special Education Teacher	1	10	n/a
	Administrative Staff	1	5	n/a
Focus group 2 (n=8)	Occupational Therapist	2	4	4.24
	Special Education Teacher	3	6.67	5.51
	Other (Behavior Analysist)	1	2	n/a
	Other (Direct Support Professional)	2	2.75	3.18
Individual interviews (n=2)	Administrative Staff (Organizational Executive Leadership)	1	49	n/a
	Other (Special Education Professor)	1	40	n/a

2.1 Participants

The study included 40 participants who were professional caregivers with the potential to use VR MSE and integrate them into the daily activities, education, therapy sessions of their children, students, or patients with neurodevelopmental disorders. Participants were included based on their professional roles, and engagement with supporting individuals with NDD, as specified inclusion criteria in the consent form and recruitment materials. These caregivers represented a group of multi-professionals, including but not limited to occupational therapists, special education teachers, administrative staff, and applied behavior analysts.

Initially, data were collected from 57 caregivers. However, data from 40 responses were used for analysis after we excluded incomplete responses having more than 50% of missing data points. Table 1 provides an overview of the participants' roles. On average, the participants had been engaged in their identified roles for 8.94 years (SD=9.21), with a range from 12 to 521 months.

From the participants who completed the questionnaire, individuals were invited to interview sessions. A total of 16 professional caregivers further volunteered to take part in semi-structured interviews, either in the form of focus groups or individual interviews based on their availability and preferences. Among them, two experts were purposefully selected for individual interviews due to their extensive professional experience in supporting individuals with NDD. Table 2 shows the composition of the interviews and focus groups.

2.2 Procedure

Data were collected in June 2024 from organizations in South Korea that provide education and services for individuals with NDD in academic and residential settings. After obtaining Institutional Review Board (IRB) approval from University of Oklahoma, participants were recruited through purposeful sampling on a voluntary basis. Recruitment materials, consisting of an invitation letter, study description, and eligibility criteria, were distributed via email to directors and program coordinators at relevant organizations. All participants provided informed consent before proceeding with the study. Introduction presentation and demonstration on the use of the VR MSE were provided to the caregivers. Members of the research team were on hand to provide technological support throughout the presentation. Following the presentation, participants were invited to complete a questionnaire. Those interested in participating in the next phase were given the opportunity to experience the VR MSE and subsequently participated in a semi-structured interview. Interview was proceeded afterward that same day, either individually or in focus group settings. All interviews were audio-recorded with participants' consent, using a mobile device to ensure data accuracy and facilitate transcription.

2.3 Data collection and analysis

The following quantitative and qualitative data was collected and analyzed to examine professional caregivers' perceptions of VR MSE.

- *Technology acceptance model (TAM):* TAM was used to explain and predict behavioral intention and use of VR MSE by professional caregivers (Abu-Dalbouh 2013; Al Kurdi et al. 2020; Jeffrey 2015; Wibowo 2019). The TAM framework consists of 20 items, including 6 items for perceived usefulness (PU), 6 items for perceived ease of use (PEU), 3 items for attitude to use (AU), and 5 items for intention to use (IU). The items were adapted from validated sources (Abu-Dalbouh 2013; Al Kurdi et al. 2020; Davis 1989; Jeffrey 2015; Wibowo 2019). Each item was rated using a 7-point Likert scale, ranging from "1" (extremely unlikely) to "7" (extremely

Table 3 Questionnaire

*Technology acceptance model
Rated from extremely likely (7) to unlikely (1)
Perceived usefulness (PU)
PU1: Using a VR MSE would enable me to accomplish the goal of meeting the visual, auditory sensory needs of individuals with NDD
PU2: Using a VR MSE would improve my performance by helping individuals with NDD in their visual, auditory sensory processing
PU3: Using a VR MSE would increase my productivity in my role while interacting with individuals with NDD
PU4: Using a VR MSE would enhance effectiveness in dealing with the sensory overload experienced by individuals with NDD
PU5: Using a VR MSE would make individuals with NDD easier to be calm
PU 6: I would find VR MSE useful in helping individuals with NDD when they display behaviors that indicate distress or unmet needs, such as prototypical, repetitive, aggressive behaviors
Perceived ease of use (PEU)
PEU1: Learning to operate a VR MSE would be easy for individuals with NDD
PEU2: Individuals with NDD would find it easy to use a VR MSE as desired
PEU3: Individuals with NDD would find interaction with VR MSE would be flexible
PEU4: Individuals with NDD would find VR MSE would be clear and understandable
PEU5: It would be easy for individuals with NDD to become skillful at using VR MSE
PEU6: Individuals with NDD would find VR MSE easy to use
Attitude to use (AU)
AU1: It is a wonderful idea to use VR MSE
AU2: I have positive feelings toward VR MSE in general
AU3: It is positive for my child to use VR MSE
Intention to use (IU)
IU1: I intend to let individuals with NDD be a user of VR MSE
IU2: I plan to let individuals with NDD use VR MSE in the future
IU3: I intend to introduce the VR MSE to other people who are users of physical/natural multisensory rooms
IU4: Individuals with NDD will be keen to use VR MSE
IU5: Individuals with NDD will be willing to use VR MSE several times in a day
**Personal wellbeing index—intellectual disability 3rd edition (PWA-ID)
Rate from happy (2), neither happy nor sad (1), sad (0)
"How happy would Individuals with NDD feel about… (after using VR multisensory room)?"
Their life as a whole
Their health
The thing they have
The thing they learn
Getting on with the people they know
How safe they feel
Doing things outside their home
How things will be later on in their life

*TAM adapted from Davis (1989), Abu-Dalbouh (2013), Jeffrey (2015), Wibowo (2019), Al Kurdi et al. (2020). Cronbach's Alpha = 0.946;

**PWA-ID adapted from Cummins and Lau (2005), Misajon et al. (2016). Cronbach's Alpha = 0.907

likely), with 4 representing a neutral response (Table 3). Cronbach's alpha was calculated to check reliability of the measure (Cronbach's Alpha = 0.946).

The Structural Equation Model (SEM) was analyzed using JASP and lavaan syntax to examine the hypothesized relationships among key constructs within TAM: PU, PEU, AU, and IU (Rogers 2024). SEM is useful for analyzing TAM variables because it provides a framework for testing complex relationships between latent variables in theoretical model while analyzing both direct and indirect effects between variables a (Gefen et al. 2000; Hamutoğlu et al. 2024). A combination of goodness-of-fit index (GFI) cutoff value of 0.89 and the standardized root mean square residual (SRMR) cutoff value of 0.09. was used to determine the degree of fit between the model and data (Cho et al. 2020). Accordingly, a $GFI \geq 0.89$ and an $SRMR \leq 0.09$ are considered an acceptable level of model fit. Additionally, descriptive statistics, mean scores and standard deviations, were calculated for the Likert scale responses to further inform professional caregivers' degree of acceptance.

- *Personal wellbeing index—intellectual disability 3rd edition (PWA-ID; reduced-choice scale):* The PWA-ID is a tool used to assess personal well-being, defined as feelings of happiness or satisfaction about one's life (Table 2). While originally intended for self-administration, this study adapted the items to gather professional caregivers' perspectives on the potential impact of VR MSE on the well-being of individuals with NDD. For example, the original question, "How happy do you feel about your life as a whole?" was revised to, "How happy would individuals with neurodevelopmental disorder feel about their life as a whole after using VR multisensory room?" Each item was rated using a 3-point Likert scale with the options: "0—sad", "1—neither happy nor sad", and "2—happy".

  For analysis, individual scores were adjusted using the following formula:

$$AdjustedScore = (Score \div X) \times 100$$

where X represents the highest possible score on the used Likert scale from 0 to X (Cummins and Lau 2005; Misajon et al. 2016). Following the adjustment, average scores were calculated for each item. The results were interpreted using the reported normative range for Western means, where scores lower than 70 indicate below-average well-being, scores between 70 and 80 indicate average well-being, and scores higher than 80 indicate above-average well-being (Cummins and Lau 2005; Misajon et al. 2016). To test internal consistency,

Table 4 Semi-structured Interview

What do you think are the benefits of the VR MSE?
When/where would you like to use the VR MSE?
What do you think are the concerns of the VR MSE?
Have you observed or do you anticipate any discomfort experienced by individuals with NDD while using the VR MSE?
Have you observed or do you anticipate any signs or symptoms of cybersickness?
Do you have any feedback regarding the VR MSE design?
What sensory features do you want to add or remove?
How do you think the user interface can be designed to enhance interaction with sensory features for individuals with NDD?

Cronbach's alpha was calculated for the measure (Cronbach's Alpha = 0.907).

However, it must be clearly acknowledged that the PWI-ID is not designed for proxy measures. Therefore, the data collected in this study using caregiver responses should be interpreted with caution. These scores are not intended to represent actual well-being levels of individuals with intellectual disabilities, but rather professional caregivers' perception of how VR MSE might affect those individuals' quality of life.

- *Qualitative interview*: Two researchers, YY and AB, conducted interviews, thematic analysis, and collaboratively triangulated the findings. Semi-structured interviews (n = 16) were conducted to gather the caregiver's perception regarding the benefits, concerns, and design recommendations for VR MSE (Table 4). Open-ended questions were used to elicit deeper insights. The entire interview was audio-recorded, and a verbatim transcription of the responses was produced using Otter.ai, with manual review by the researchers (Otter.AI, n.d.).

  Thematic analysis was employed to analyze the qualitative data (Braun and Clarke 2006; Clarke and Braun 2021). This study used a generative AI tool, ChatGPT (OpenAI 2025), to assist with the thematic analysis process. According to Christou (2024), generative AI can support various stages of thematic analysis: familiarization with the research data, generation of initial codes, searching for/reviewing themes, theme definition, creating conceptual diagrams, and producing final report.

  In this study, AI assistance was specifically applied to generate initial codes, identify themes, and extract relevant quotes. The thematic analysis process started with researchers entering the thematic analysis steps proposed by Braun and Clarke (2006) into the generative AI tool, with the prompt "identify thematic analysis steps." After the researchers reviewed the AI-generated steps aligned with those outlined in the Braun and Clarke's (2006) research, the interview transcripts were entered with prompts to "follow the thematic analysis steps and generate recurring codes and themes in the interview transcript". Next, researchers reviewed and refined the generated themes. To extract supporting data, an additional prompt was used: "identify quotes from interview transcripts that exemplify each theme." Throughout this process, two researchers independently reviewed all AI-generated content, cross-verifying it against the original interview transcripts to ensure accuracy and validity. Adjustments to the codes and themes were made as necessary during this process. For instance, some codes and thematic labels were regrouped and refined for conceptual clarity, or alternative quotes were selected to precisely represented participant intent.

3 Results

3.1 Technology acceptability of VR MSE (aim 1)

The survey responses were analyzed to assess professional caregivers' acceptability of the VR multisensory environment (MSE) using the Technology Acceptance Model (TAM). Structural equation analysis on the full TAM model (Fig. 2) indicated a poor model fit with the collected data (GFI = 0.852, SRMR = 0.108). To understand the underlying relationships, this study tested each hypothesized relationship between key constructs, including perceived ease of use (PEU), perceived usefulness (PU), attitude to use (AU), and intention to use (IU) (Table 5).

Table 5 Regression Results of TAM Hypotheses

Hypothesis	β	Std.Error	z	*p**	R^2	GFI**	SRMR***	α****
H1.PEU → PU	0.369	0.148	2.503	0.012	0.137	0.951	0.083	0.907
H2.PEU → AU	0.295	0.182	1.622	0.105	0.070	0.975	0.091	0.898
H3.PU → AU	1.196	0.222	5.388	< .0.001	0.667	0.944	0.075	0.941
H4.PU → IU	1.087	0.247	4.403	< .0.001	0.638	0.943	0.071	0.931
H5.AU → IU	0.769	0.132	5.845	< .0.001	0.688	0.948	0.099	0.931

*$p < 0.05$ indicates statistical significance (Tenny and Abdelgawad 2023)

**Goodness of Fit Index (GFI): ≥ 0.89 represents a good fit, 0.89 > GFI ≥ 0.85 indicates an acceptable fit (Cho et al. 2020)

***Standardized Root Mean Square Residual (SRMR) ≤ 0.09 indicates a good fit (Cho et al. 2020)

****Cronbach's alpha (α ≥ 0.90 reflects excellent reliability, ≥ 0.80 indicates good reliability (Tavakol and Dennick 2011)

Fig. 3 Path analysis: PEU→PU

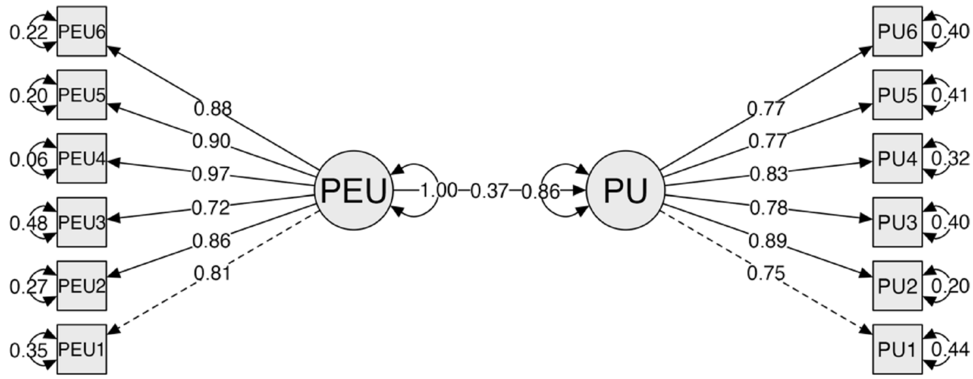
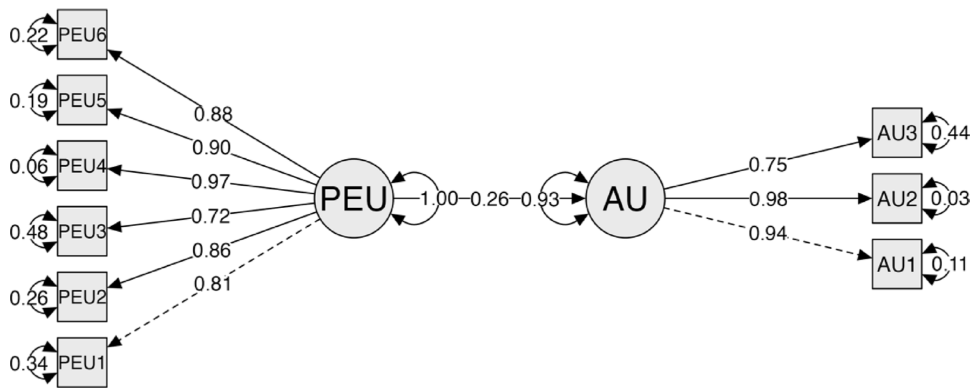


Fig. 4 Path analysis: PEU→AU



3.1.1 H1. Perceived ease of use (PEU) has a significant effect on the perceived usefulness (PU)

The structural equation model revealed a significant positive path between PEU and PU (β = 0.369, SE = 0.148, z = 2.503, p = 0.012), supporting the hypothesis that greater ease of use increases perceived usefulness. The GFI and the SRMR indicated a good fit, the reliability coefficient (α = 0.907) indicated excellent internal consistency. This result suggests that the relationship is statistically significant and captured within the model's structure (Fig. 3).

3.1.2 H2. Perceived ease of use (PEU) has a significant effect on attitude to use (AU)

The path from PEU to AU was not significant (β = 0.295, SE = 0.182, z = 1.622, p = 0.105), indicating that the perceived easiness of the technology does not directly relate to actual use. The fit indices (GFI = 0.975, SRMR = 0.091) showed an excellent GFI but a slightly high SRMR value, indicating potential minor misfit in capturing this relationship. The reliability (α = 0.898) was high, confirming good internal consistency in measurement. Despite this, the lack of statistical significance for the path itself suggests that ease of use alone may not a predictor of actual use, highlighting the need to consider additional factors in explaining technology adoption (Fig. 4).

3.1.3 H3. Perceived usefulness (PU) has a significant effect on attitude to use (AU)

A strong and significant path was found between PU and AU (β = 1.196, SE = 0.222, z = 5.388, p < 0.001), confirming that perceived usefulness is a predictor of actual use. The indices (GFI = 0.944, SRMR = 0.075, α = 0.941) suggested a good fit and excellent reliability. This result aligns with prior research on technology acceptance models (Davis 1989; Abu-Dalbouh 2013; Jeffrey 2015; Wibowo 2019; Al Kurdi et al. 2020) (Fig. 5).

3.1.4 H4. Perceived usefulness (PU) has a significant effect on intention to use (IU)

The path from PU to IU was significant (β = 1.087, SE = 0.247, z = 4.403, p < 0.001), indicating that users who perceive the system as useful are more likely to intend to use it. The model fit indices (GFI = 0.943, SRMR = 0.071) indicated a good model fit, and reliability coefficient (α = 0.931) demonstrated excellent internal consistency (Fig. 6).

3.1.5 H5. Attitude to use (AU) has a significant effect on intention to use (IU)

A strong and significant effect was observed between AU and IU (β = 0.769, SE = 0.132, z = 5.845, p < 0.001),

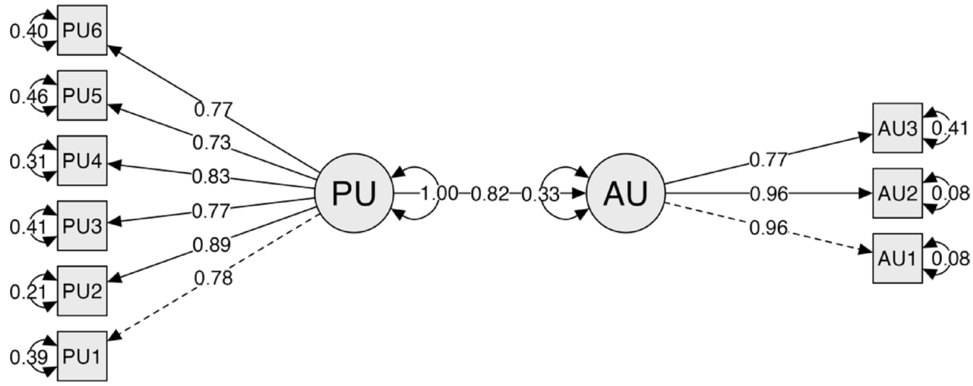


Fig. 5 Path analysis: PU→AU

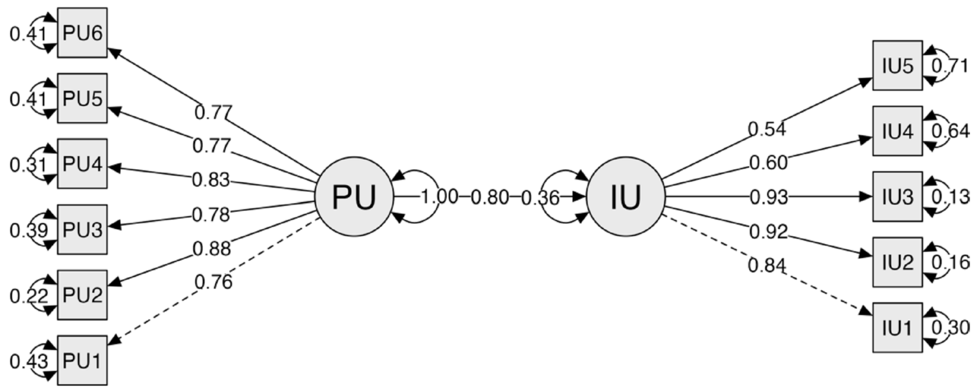


Fig. 6 Path analysis: PU→IU

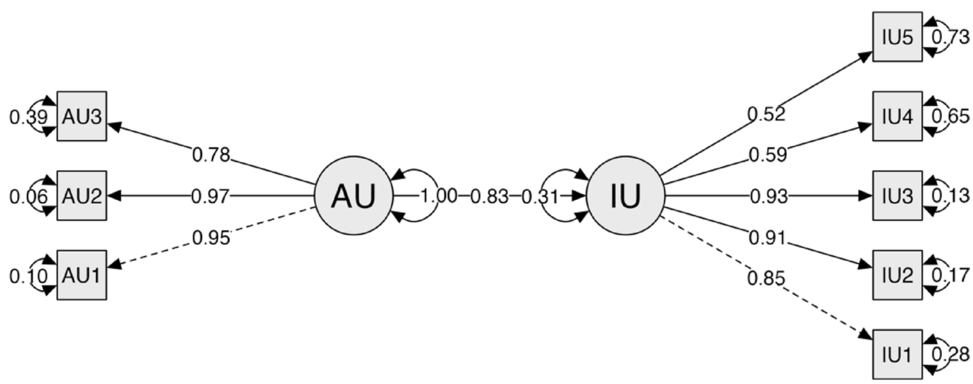


Fig. 7 Path analysis: AU→IU

supporting the hypothesis that actual use positively influences intention to use. While the reliability coefficient ($\alpha = 0.931$) showed a good internal consistency. the model fit indices (GFI = 0.948, SRMR = 0.099) demonstrated a borderline fit. This indicates that while the relationship itself is statistically supported, the overall model structure may not fully represent underlying patterns (Fig. 7).

3.1.6 Descriptive analysis

Descriptive statistics indicated professional caregivers' overall positive acceptability of VR MSEs for NDD (6). Regarding each construct within TAM, professional caregivers reported high level of agreement on attitude toward use (M = 5.37, SD = 1.38) and intention to use (M = 5.01, SD = 1.18). This result suggests a high potential for professional caregivers to integrate VR MSE into daily activities and therapy sessions for individuals with NDD. Moderate agreement was observed on the perceived usefulness of VR MSE in supporting varying sensory needs of individuals with NDD (M = 4.98, SD = 1.14). While the perceived ease of use received a favorable score (M = 4.27, SD = 1.26), it was the lowest among the constructs. This may reflect differing levels of technological familiarity among professional caregivers and highlights opportunities to enhance the intuitive design of the VR MSEs (Table 6).

This study further analyzed perception by different professional caregiver sub-groups. The comparison of TAM construct scores across professional caregiver groups revealed emerging patterns (Fig. 8). For instance, special

Table 6 Descriptive statistics: caregiver technology acceptability of VR MSE

	Mean	Std. Deviation	PU	PEU	AU	IU
Perceived usefulness (PU)	4.98	1.14	1			
Perceived ease of use (PEU)	4.27	1.26	0.354*	1		
Attitude to use (AU)	5.37	1.38	0.816***	0.335*	1	
Intention to use (IU)	5.01	1.18	0.731***	0.438**	0.821***	1

Mean scores between 5 and 7 indicate strong agreement or positive perception; scores between 4 and 5 indicate moderate agreement; and scores below 4 indicate weak agreement; $*p<0.05$, $**p<0.01$, $***p<0.001$; Pearson's r values indicate correlation strength: $0.5<|r|$ strong, $0.3<|r|<0.5$ moderate, $0.1<|r|<0.3$ weak (Cohen 1988)

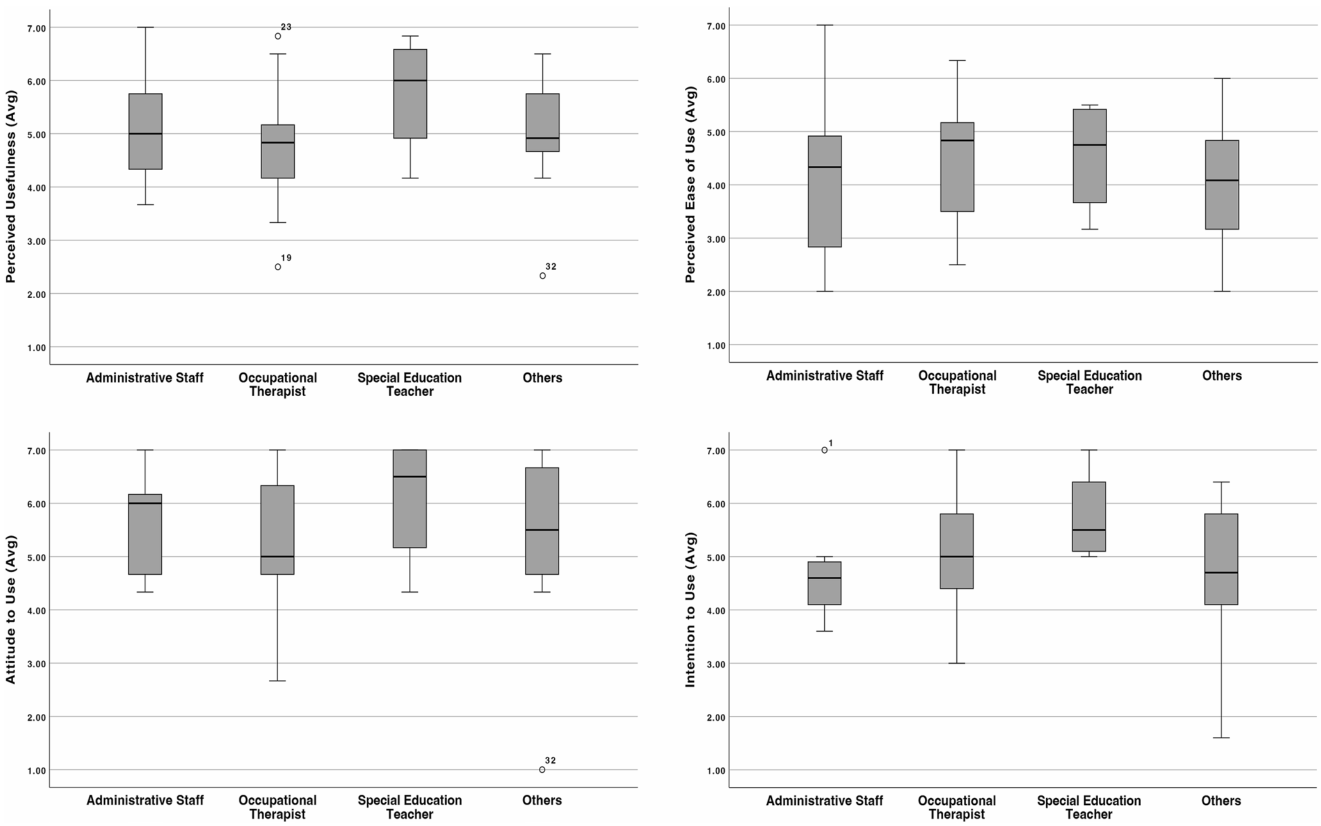


Fig. 8 TAM by caregiver groups

education teachers consistently reported the highest median scores for PU, PEU, AU, and IU, suggesting a strong overall acceptance of the VR MSE. Occupational therapists also tend to demonstrate high scores across all constructs, indicating positive perceptions and a strong inclination to integrate the VR MSE into their practice. Administrative staff, while slightly lower in median scores than the special education teachers and occupational therapists, exhibited relatively consistent responses and a generally favorable view of the technology. The "Others" group showed the lowest median scores across the constructs. Overall, these findings suggest that special education teachers and occupational therapists are more inclined to adopt the technology.

3.2 VR MSE and well-being of individuals with NDD (Aim 2)

Professional caregivers anticipated that VR MSEs would positively impact the well-being of individuals with NDD. The perceived well-being scores, measured by Personal Wellbeing Index-Intellectual Disability 3rd Edition (PWA-ID), indicated average or above-average outcomes in various domains, such as life as a whole, health, the thing they have, the things they learn, doing things outside their home, and how things will be later in their life (Table 7). However, it is important to note that the PWA-ID is intended for self-report by individuals with intellectual disabilities, not for completion by others on their behalf. Responses provided by proxies, such as professional caregivers in this study, are not for measuring the subject's well-being itself (Cummins

Table 7 Caregivers' Perceptions on the Impact of VR Multisensory Environments on Personal Well-being of Individuals with NDD (n=40)

Personal Well-being	Mean	Std. deviation	Adjusted Mean (out of 100)
Life as a whole	1.61	0.80	80.26
The things they have	1.50	0.08	75.00
Health	1.47	0.08	73.68
Doing things outside their home	1.47	0.08	73.61
How things will be later in their life	1.44	0.08	72.22
The things they learn	1.42	0.08	71.05
How safe they feel	1.32	0.08	66.22
Getting on with the people they know	1.29	0.07	64.47

Adjusted mean < 70: below-average well-being, 70–80: average well-being, > 80: above-average well-being (Cummins and Lau 2005; Misajon et al. 2016)

Table 8 Thematic analysis: Caregivers' perspectives

Themes	Concerns	Design recommendations
Sensory customization	Customizable options for sensory stimuli (e.g., calming vs. stimulating) Personalized interaction stages/sequences	Incorporate selectable stimulation/calming levels More adjustable sensory elements (e.g., brightness, sound levels, color schemes) Enable user customization, create modular programs, and offer staged levels of interaction
Sensory simulation quality	Realistic virtual experience	Exploring advanced technologies for tactile feedback Realistic simulations (e.g., colors, lights, sound)
Intuitive interface design	Operating and navigating VR interface	Simplify the interface (e.g., use of large, simple buttons within view range) Provide visual guidance
Use of VR device	Potential resistance to headsets due to sensitivity Potential cybersickness	Seek alternatives (e.g., light-weight goggles)
User characteristics	Wide variation in user abilities Dependence on caregivers, therapists, and teachers for proper use	Good fit for intellectual, emotional difficulties, Potential limitations for users with motor coordination difficulties Offer remote guidance options

and Lau 2005). Therefore, the findings should be interpreted carefully, as they represent caregivers' perceptions rather than direct input from individuals with NDD themselves.

3.3 VR MSE design strategies (Aim 3)

A total of 108-min interview transcripts were used for thematic analysis. The analysis identified six key themes: sensory customization, sensory simulation quality, intuitive interface design, use of VR device, and user characteristics. Table 8 summarizes the themes, including benefits and concerns discussed by potential users, and design recommendation to enhance VR MSE experiences.

3.3.1 Sensory customization

Caregivers highlighted the benefit of VR MSE, mentioning "Children could benefit from selecting the stimuli, atmosphere, or environment they prefer." This flexible and customizable nature of VR experience provides opportunities for personalized relaxation and stress reduction. Participants emphasized the need for more diverse customizable options for sensory stimuli to support diverse user preferences. For example, some users may require calming environments, while others may benefit from more stimulating ones. One participant suggested, "Instead of letting them choose randomly, you could have programs tailored to specific stimulation levels." Another added, "Having stages or color options would be better for children with [mild] intellectual abilities." These comments advocate for more personalized and modular design options to support different user needs.

Personalized interaction stages and sequences were also highlighted as a key requirement to enhance the user experience. Therefore, design recommendations include incorporating selectable stimulation or calming levels, offering more adjustable sensory elements such as brightness, sound levels, and color schemes, and enabling user customization through modular programs and staged levels of interaction.

3.3.2 Sensory simulation quality

The quality of sensory simulation was a concern, with participants stressing the importance of creating a realistic virtual experience. A participant pointed out the need for realistic simulations of elements like colors, lights, and sounds, mentioning "Those need to really sparkle and show the right colors [as the physical sensory room offers]." The importance of tactile feedback was also repeatedly raised, noting "In the real space, there will be tactile sensations. Something fluffy and soft, a feeling when you touch it, something like that." These insights highlight the need for advanced technologies that simulate sensory features to bridge the gap between virtual and real-world experiences.

3.3.3 Intuitive interface design

Ease of use and intuitive navigation were other concerns raised during the interviews. One participant highlighted, "It [the selection buttons] needs to be visually striking, providing reinforcement. Something that makes them think, ‘I want to press that again.’" Another added, "Simpler is better. Large buttons and clear options will help users who may have motor difficulties." To address these concerns, the design should include a simplified interface with large, easy-to-use buttons and clear visual guidance to support users with varying abilities.

3.3.4 Use of VR device

Concerns about the VR device primarily raised regarding potential resistance to headsets and the risk of cybersickness. One participant noted, “It seems very difficult to keep it [the headset] on them [children].” The other professional caregiver suggested, “If you can find a way to do it without the headset, you can provide services to a wider range of people” Additionally, sensitivity issues with the headsets were highlighted. To mitigate these issues, lightweight goggles and alternative display methods, such as VR cave and large-screen projections, should be explored. In addition, limiting the duration of VR sessions or incorporating breaks may help reduce discomfort and cybersickness for users with heightened sensory sensitivities.

3.3.5 User characteristics

The diverse characteristics of users with neurodevelopmental disabilities were a recurring theme. Participants pointed out that user abilities vary widely, with some users requiring significant assistance. A professional caregiver mentioned, “Children with autism tend to process visual cues well, so I don’t think it would be a big problem.” Another participant observed, “For individuals with developmental disabilities, if coordination is difficult, or operating machines is difficult, or spatial awareness is difficult, I think we need to supplement it somehow.” These comments suggest that the system must accommodate varying levels of cognitive and motor abilities.

In such cases, dependence on professional caregivers, therapists, and teachers for proper use was also emphasized. One professional caregiver commented, “Teachers or caregivers are important. No matter how well it’s developed, if the supporter understands it well and facilitates its proper use, it would be great.” Another noted, “A therapist’s role seems crucial when using Snoezelen. They tend to guide the experience rather than letting individuals explore freely.” Design recommendations include ensuring the VR system is suitable for users with intellectual and emotional difficulties, offering remote guidance options, and accommodating users with motor coordination challenges. This also suggests that training for support staff is essential.

4 Discussion

This study provides insights into the acceptability and feasibility of VR multisensory environments (MSEs) for individuals with NDD. In this section, acceptability is discussed based on the results of TAM and PWI-ID, and the feasibility based on qualitative interview data.

4.1 Acceptability

The findings from TAM analysis the overall positive acceptance of VR MSE among professional caregivers, consistent with previous research (Mills et al. 2023b). The perceived usefulness of the system significantly influenced both attitude and intention to use. This aligns with the TAM hypothesis (Abu-Dalbouh 2013; Davis 1989; Hamutoğlu et al. 2024), suggesting that professional caregivers are likely to adopt VR MSEs when they perceive them as beneficial for individuals with NDD.

However, perceived ease of use (PEU) did not have a direct effect on AU (H2), indicating that professional caregivers found VR MSEs moderately easy to use and usability alone was not a primary factor in shaping their attitudes to use this technology. The path analysis for this hypothesis demonstrated borderline model fit, thus, future analysis with larger sample size will be beneficial to refine the relationship. The relevant theme regarding easiness of using VR MES was identified from qualitative interview. Caregivers suggested that simplifying the interface and providing visual cues within view range, and repetitive use will increase ease of use and confidence (Mills et al. 2023b).

Caregivers, particularly special education teachers and occupational therapists, demonstrated higher acceptance of VR MSEs than other groups of professional caregivers, reflecting that VR MSEs might be useful for therapeutic and educational applications. However, varying score range within each question suggests familiarity with technology plays a role in adoption, emphasizing the need for training and support to ensure successful implementation (Mills et al. 2023b).

4.2 Feasibility

The results from the PWI-ID supported the feasibility of VR MSEs, as professional caregivers perceived positive impacts on the well-being of individuals with NDD. Caregivers anticipated the improvements across multiple well-being domains, including "life as a whole," "the things they have," "ealth," and "engagement in activities outside their home," etc., with scores falling within the average or above-average well-being range. These findings, while suggesting the potential of VR MSEs to support diverse sensory needs of individuals with NDD, relies on perceived benefits, measured indirectly (Mills et al. 2023a; b).

The qualitative findings further explored professional caregivers' insights on feasibility of VR MSE, considering the importance of professional caregiver involvement in the design process. Themes such as sensory customization, intuitive interface design, and the role of professional caregivers and therapists highlight the need for a user-centered approach. This approach aligns with the broader literature on the significance of co-design in creating effective interventions for individuals with NDD (Kashyap and Vishwakarma 2023). Incorporating customizable sensory elements and realistic simulations can help enhance sensory experience of individuals with NDD. Also, concerns about device-related challenges, and varying user abilities require careful attention to design and implementation strategies in the future.

4.3 Implications

Professional caregivers' perceptions highlighted the potential of VR MSE as an alternative or complementary tool to traditional MSEs. While VR MSE may not fully replace physical MSEs in aspects of tactile input, body movement, body awareness modalities, and realistic simulation quality, VR can offer a feasible, affordable substitute in contexts where its access is constrained by spatial and/or financial limitations.

Several design considerations, such as sensory customization and intuitive interface, indicates that VR MSE tools must be adaptable to accommodate the diverse sensory processing profiles of individuals with NDD. Clinicians and therapists can benefit from VR MSE that allows flexible configuration of stimuli, enabling personalized exposure based on the user's preference, tolerance, and comfort levels.

Ergonomics and physical comfort are also essential when using VR devices. Factors including headset weight, strap tightness, facial pressure points, and auditory equipment positioning, should be carefully considered. Lightweight headsets with soft padding and open-ear options may enhance comfort for those with tactile or auditory sensitivities.

Furthermore, successful application of VR MSEs requires support of adequate training and resources for professional caregivers. This training could include helping caregivers recognize signs of discomfort or cybersickness, adjust sensory settings based on individual needs, and guide users through the VR interface. Although the study found high level of perceived usefulness, the variability in ease-of-use scores suggest the importance of technical training and user-friendly design for effective adoption.

4.4 Limitation and future study

While this study provides insights into the acceptability and feasibility of VR MSE, the following aspects should be considered when interpreting the findings. Firstly, this study included a small number of participants (n = 40), which may have contributed to the poor model fit observed in the SEM analysis of full Technology Acceptance Model (TAM). It is also important to note that the professional caregiver groups primarily consisted of caregivers such as occupational therapists, special education teachers, organizational administrate staff in educational and residential settings. This sample may not fully represent the broader caregiver population, such as parents or general education teachers, or other healthcare professionals. In addition, this study has not collected demographic information about the NDD population supported by participants, such as age, disability diagnosis, as well as their prior experience with VR, which can potentially influence perception of professional caregivers. Despite this limitation, the individual hypothesis testing approach provided meaningful insights into the key relationships in TAM. However, future research should incorporate a larger, diverse sample, detailed demographic information to enhance the generalizability and validity, as well as provide opportunity to further examine group differences (e.g., technology acceptability based on roles, years of experience, etc.).

Additionally, while cybersickness and sensory sensitivities were identified as concerns, this study did not include a formal assessment of adverse effects such as motion sickness, fatigue, or cognitive overload. Future research should integrate objective cybersickness scales and sensory processing measure to evaluate potential positive and negative effects of VR MSE.

Lastly, this study examined the professional caregiver perspective rather than direct user experience. Although professional caregivers play a crucial role in implementing VR interventions, understanding the firsthand experiences of individuals with NDD is essential. Future research needs to include direct involvement of individuals with NDD in

VR MSE evaluation. Integrating advances in technologies, the collection of biometric data, such as eye movements, body movements, and haptic interactions, will provide opportunities to better understand the behavior of individuals with NDD and address their needs.

5 Conclusion

This study demonstrates the feasibility and acceptability of VR MSEs to enhance the quality of life for individuals with NDD by addressing their varying sensory needs. The finding shows that VR MSE have potential to serve as an alternative or supplement to traditional MSEs, particularly in settings where space and financial constraints limit its accessibility. While capturing professional caregivers' positive perspectives on VR MSE, this study also revealed the necessity of addressing technical and design-related enhancement, such as ease of use and sensory customization, to maximize the benefits of VR MSEs. In this process, professional caregiver involvement, continued feedback, and iterative design are essential for developing a successful VR MSE solution.

Future research should further conduct more detailed analyses across broader range of professionals, including those in healthcare settings. Comparing perspectives among different professional groups will help guide the targeted application of VR MSE in diverse settings. Moreover, it is crucial to evaluate the effectiveness and impact of VR MSEs on well-being using direct measure of end-users' behavioral outcomes and biometric responses. Investigations can also assess their long-term effectiveness. Additionally, efforts to enhance training and support for professional caregivers will be critical to ensuring effective adoption and use of VR MSEs. By fostering collaboration between designers, professional caregivers, and users, VR MSEs can be a valuable tool for improving the lives of individuals with NDDs.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors declare no competing interests.

Ethics approval and consent to participate This study was conducted in accordance with ethical guidelines and received approval from the University of Oklahoma Institutional Review Board (OU IRB-Norman), under approval number 17151. All participants were informed about the purpose, procedures, potential risks, and benefits of the study before providing their consent. Written informed consent was obtained from all participants prior to their participation in the study.

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