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REVIEW ARTICLE

Perception and experience of multisensory environments among neurodivergent people: systematic review

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ABSTRACT

A multisensory environment (MSE) is an adaptable, interactive space that allows individuals with sensory processing differences to explore diverse sensory stimuli depending on their needs. Despite their demonstrated benefits, there has been little evidence-based design approach for MSE design. This systematic review aims to synthesize how neurodivergent individuals perceive and experience MSE and provides design implications for creating MSE that meets the diverse sensory preferences and needs. The review process follows the PRISMA protocol. The review included 27 studies published in peer-reviewed journals between 2013 and 2023. Findings highlight MSE design strategies with key themes: sight, hearing, touch, smell, taste, body movement, and body awareness. These environmental factors within MSE are explained in relation to user experience such as adaptive sensory-response behaviours and psychological well-being. The identified MSE design strategies will contribute to guiding designers and researchers with evidence-based design approaches that maximize the benefits of MSEs for neurodivergent people.

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KEYWORDS
multisensory environments; sensory room; Snoezelen; sensory integration theory; neurodivergent; evidence-based design

Introduction

Sensory processing refers to the neurological process by which the human brain and body perceive, interpret, and respond to internal and external information received through the senses. Sensory processing is crucial for daily functioning, self-regulation, and social interaction (Yi and Ellis 2023; Ellis and Yi 2023; Yi, Boeck, and Ellis 2018; Ayres 1972). Given the critical role of sensory processing in shaping individuals' interactions with their environments, Sensory Integration Theory (SIT) focuses on how the brain processes sensory information (Ayres 1972; Roley et al. 2007). SIT identifies seven sensory systems, including sight (visual), hearing (auditory), touch (tactile), smell (olfactory), taste (gustatory), body movement (vestibular), and body awareness (proprioceptive). In this context, sensory perception is defined as the sensory input received by individuals through various sensory modalities, while sensory experience refers to the subjective interpretation and response to these sensory inputs (Coren, Ward, and Enns 2004). SIT provides a foundational perspective for designing environments that focus on diverse sensory needs.

SIT is also relevant to sensory processing variations, such as sensory over-responsivity (SOR) and sensory under-responsivity (SUR). SOR refers to heightened sensitivity toward sensory stimuli, triggering exaggerated reactions. On the other hand, SUR involves unawareness or non-responsiveness to sensory input, often seeking intense stimulation and displaying repetitive behavioural patterns. SOR or SUR can negatively affects long-term functioning, learning, self-regulation, and social interaction, sometimes resulting in behaviours like self-stimulation or aggression, limiting participation in society (Cuvo, May, and Post 2001; Hens 2021; Ben-Sasson et al. 2009).

Sensory processing involving SOR or SUR impact between 5% and 16.5% of the general population (Miller et al. 2017), with higher prevalent among neurodiverse individuals. Neurodiversity regards neurological differences as natural human variations in brain function (Hens 2021). In this manner, neurodivergent refers to people with neurological differences and MSEs offer environments that accommodate their various neurological processing styles. This group includes people with a variety of neurological and cognitive conditions (Miller et al. 2009), such as autism spectrum conditions (ASC), learning disabilities, attention deficit hyperactivity disorder (ADHD) (Green et al. 2016), and cognitive conditions like dementia (Örulv 2023).

SIT has explored different sensory patterns using neurological understanding of sensory processing and identified supportive environments through empirical research to accommodate varying sensory needs (Ayres 1972; Smith Roley et al. 2007). The underlying hypothesis is that the systematic sensory exploration can support the individual's nervous system's ability to interpret and respond to sensory information.

Multisensory environments

Multisensory environments (MSEs) support individuals with sensory processing differences. MSE offers diverse sensory stimuli – such as sight, hearing, touch, smell, taste, body position, and body awareness. MSEs are often equipped with technologies such as interactive screens, adjustable lighting systems, sound equipment, and tactile surfaces to create either stimulating or calming effects (Parham, Roley, and Otd 2008).

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Related concepts include Ayres Sensory Integration (ASI) and Snoezelen. ASI often involves structured sensory experiences under the guidance of a trained therapist to help regulate sensory responses, with established fidelity (Parham, Roley, and Otd 2008). Meanwhile, Snoezelen allows self-directed sensory exploration. This study uses the term MSE to include both structured and self-driven approaches to sensory experiences. The primary motivation of MSEs is to provide sensory experiences that meet the diverse needs of individuals with varying sensory processing abilities. This controlled sensory experience, either stimulate or calm the senses, supports those with SOR or SUR, helping their daily lives and enhancing well-being.

Related literature

MSE design requires a multidisciplinary approach between architectural and health sciences. Previous systematic reviews have explored sensory interventions for people with ASC (Case-Smith, Weaver, and Fristad 2015; Lang et al. 2012), children with behavioural responses linked to sensory differences (Wan Yunus et al. 2015), and people with dementia (Prins et al. 2021). Ongoing reviews registered in the International Prospective Register of Systematic Review (PROSPERO) focus on the effect of MSE on people with mental illness, ADHD, and cognitive challenges. These reviews are often from an occupational therapy point of view, providing valuable findings on intervention outcomes and their effectiveness.

However, the gap exists from the architectural science viewpoint. There has been little evidence-based design approach for MSE design that could benefit future sensory environmental design. Evidence-based design refers to a process that uses scientific research to create environments that support the best possible user experiences (Stichler and Hamilton 2008). For example, ASI fidelity measure specified six physical MSE setup guidelines (Parham, Roley, and Otd 2008). Later, Mostafa (2014) created a sensory design matrix integrating architectural design elements such as structure, balance, environmental quality, and dynamics. However, MSE design has heavily relied on low-level evidence. Therefore, the gap in the previous findings can be enhanced by extracting data regarding sensory design considerations and their relation to users' behaviours.

Purpose

The purpose of this systematic review is to synthesize how neurodivergent individuals perceive and experience a multisensory environment (MSE) and provide design implications for creating MSE for neurodivergent people. The current systematic review aims to (1) examine MSE's effects on behavioural and psychological outcomes among stakeholder groups, (2) identify multisensory environment design considerations by explaining the sensory stimuli characteristics with relation to users' experiences, and (3) offer MSE design implications for neurodivergent population.

Methods

The structure and procedure of this review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al. 2010). The Covidence, a web-based systematic review collaboration software platform, was used throughout the systematic review process.

Search strategy

Keyword searches were conducted for five academic databases including PubMed, CINAHL, MEDLINE, PsycINFO, and Web of Science. Search terms included (multisensory environment OR sensory room OR Snoezelen) AND (design). The search was restricted to full-text, peer-reviewed studies.

Inclusion and exclusion criteria

The scope of this review was defined by the study's population, intervention, comparators, and outcomes (PICO). Studies were selected using the inclusion criteria: (a) potential stakeholders of MSEs, (b) multisensory environments, (c) behavioural and psychological changes, (d) interior, (e) written in English, (f) publication dates between 2013 and 2023. The period was selected to capture the latest decade of research and to reflect recent advancements in MSE design.

The exclusion criteria were: (a) participants without neurodevelopmental or neurocognitive impairment, (b) not multisensory environments (c) exterior (e.g. urban, landscape), (d) written in non-English (e.g. Spanish), (e) published before 2013.

Selection procedure and data extraction

Following the search results, Covidence eliminated duplicate studies. Subsequently, two researchers carried out title and abstract screening, followed by full text screening based on pre-established inclusion and exclusion criteria. Researchers used a comprehensive matrix to extract data from the selected studies. Following the directed content analysis process (Assarroudi et al. 2018), MSE design considerations were coded and categorized according to sensory modulations within SIT. Emerging themes were added by analysing word cloud and frequency using NVivo (Elliott-Mainwaring 2021). Due to the small participant numbers in the studies included, a meta-analysis was not conducted. Instead, findings were presented in a narrative summary.

Quality appraisal

For each study, two investigators independently evaluated the study quality using the JBI critical appraisal tools (Tufanaru et al. 2020). JBI tools were selected according to study types; for example, randomized controlled trials (RCTs), quasi-experimental studies, cohort study, case reports, qualitative studies, expert opinion, and systematic reviews. Any disagreements between the two primary reviewers were addressed by discussion. Evidence level and strength were determined based on guidelines suggested by the American Occupational Therapy Association (2020) and the Center for Evidence-Based Medicine (2009).

Results

The PRISMA flow diagram reports the study selection process (Figure 1). The selected 27 studies consist of six randomized controlled trials (RCTs; evidence level 1B), four quasi-experimental

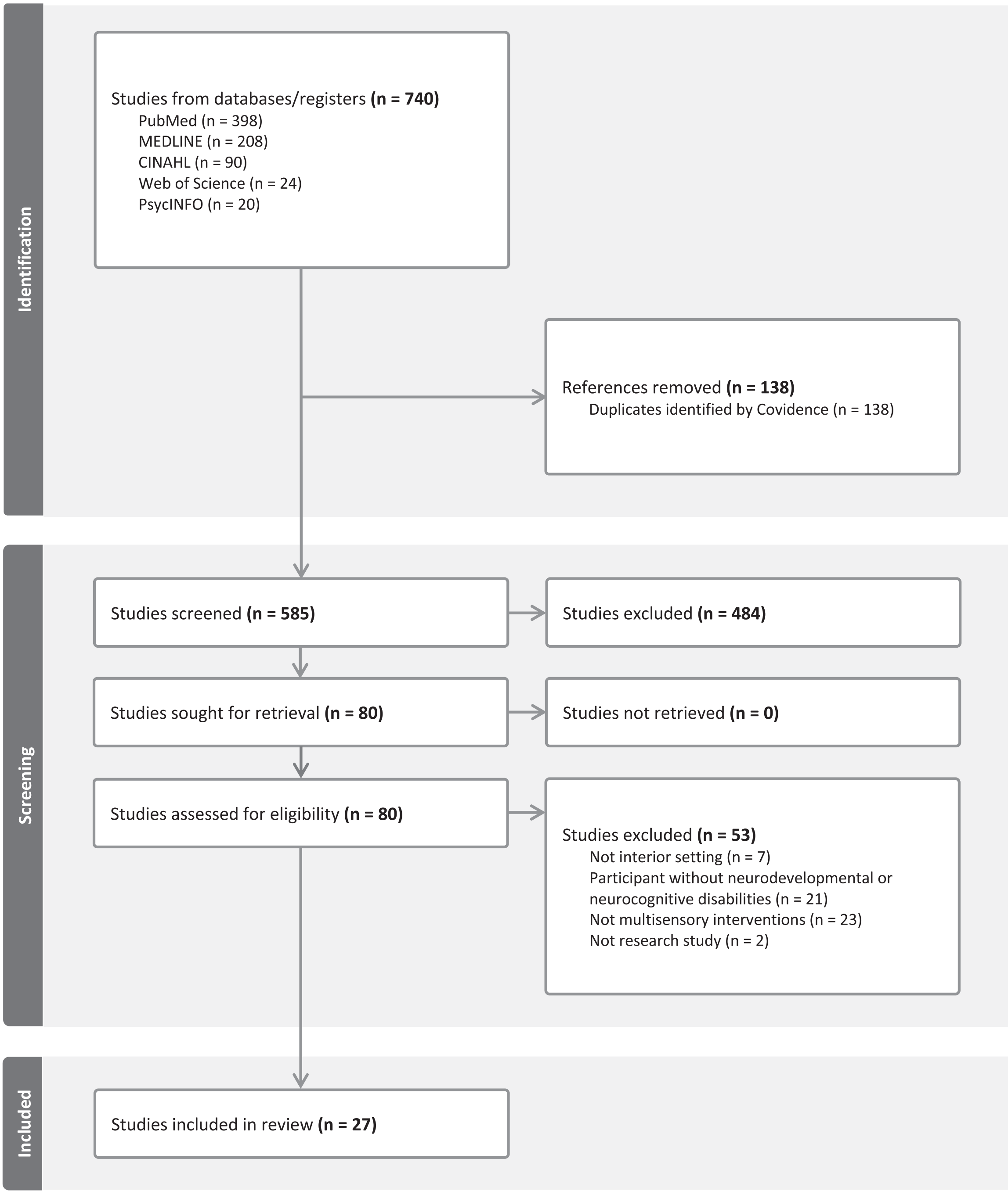

Figure 1. Study selection process. Note. Adapted from PRISMA (Page et al. 2021).

studies (evidence level 2B), two cohort studies (evidence level 3B), four case reports, four qualitative studies (evidence level 4), one expert opinion (evidence level 5), and six systematic reviews (including 1 evidence level 1A, 2 evidence level 2A, 3 evidence level 4). Table 1 describes the characteristics of the included studies. As a result of the quality appraisal, each of the included studies was rated as low or moderate risk of bias (Tables 2–8).

Multisensory environment effects

The following section examines MSE's effects on behavioural and psychological outcomes among stakeholder groups (Aim #1).

Behavioural outcomes

Agitation and Arousal. Studies have found that MSEs effectively help manage agitation and arousal. Helbling, Grandjean, and Srinivasan (2023) reported a significant reduction in agitated behaviour among adults with cognitive impairment. MSE also resulted in decreased agitation, disruptive behaviours, and aggression among individuals with dementia (Lorusso et al. 2022; Lorusso and Bosch 2018; Sánchez et al. 2013). Multiple RCTs showed significant reductions in agitation levels as measured by the Cohen-Mansfield Agitation Inventory (CMAI) with greater score in physically nonaggressive behaviour (Maseda et al. 2014a; Sánchez et al. 2016a, 2016b). Verbally agitated behaviours also indicated significant decreases (Maseda et al.

Table 1. Characteristics of selected studies.

#	Author (Year)	Study design (Evidence Level*)	Participants	Multisensory environments	Outcome
Evidence Level 1					
1	Helbling, Grandjean, and Srinivasan (2023)	Systematic review (Level 1A)	Cognitive impairment and/or special needs	MSE, multisensory stimulation therapy	**Behavioural Changes** • Significant improvement in the agitated behaviour • No overall effect on the challenging behaviour **Psychological Well-being** • Significant effect of the MSE on depression • Significantly lowered pulse rate of adults • No effect of MSE on the Quality of Life **Others** • Significant improvement in cognition
2	Maseda et al. (2014a)	Randomized controlled trial (Level 1B)	Dementia	30-minute use, twice weekly, for 16 weeks **MSE intervention group** (non-directive approach): **One-to-one activity group** (directive) **Control group:** no exposure	**Behavioural Changes** • Improvement in nonaggressive behaviours in MSE compared to activity group. • Positive effects in agitated behaviours, measured by Cohen-Mansfield Agitation Inventory (CMAI). • Significant improvement in Neuropsychiatric Inventory-Nursing Home (NPI-NH) • No significant effects on Activities in Daily Living (ADLs), measured by the Barthel index. **Psychological Well-being** • Mood and cognition: Improved but no significant differences in the Cornel Scale for Depression in Dementia (CSDD) **Others** • No significant changes in cognitive level, measured by the Global Deterioration Scale (GDS)
3	Maseda et al. (2014b)	Randomized controlled trial (Level 1B)	Dementia; Sensory Processing Differences	30-minute use, twice weekly, for 16 weeks **MSE group** (non-directive approach): **One-to-one activity group** (directive) **Control group:** no exposure	**Behavioural Changes** **Psychological Well-being** • The MSE sessions were found to be as effective as activity sessions. • Improved behaviours and mood, measure by the Interact Scale, immediately after the sessions • Improvements in items: talked spontaneously, related well to others, attentive to/focused, enjoying self, active/alert, less bored/inactive, relaxed/content • Biomedical parameters of wellbeing: decrease in heart rate, increase in oxygen saturation (SpO_2)
4	Maseda et al. (2018)	Randomised controlled trial (Level 1B)	Dementia	30-minute use, twice weekly, for 12 weeks **MSE group** **Music group:** preferred music in a quiet room.	**Psychological Well-being** **Behavioural Changes** • Improved behaviours/mood, measure by the Interact scale. • MSE group: significant improvements in items: more happy/content, related to people better, more attentive/focused, enjoying themselves, more active or alert, less bored/inactive, and more relaxed/content, and sleeping appropriately. • Biomedical parameters of wellbeing: decrease in heart rate, increase in oxygen saturation (SpO2).

(*continued*).

Table 1. Continued.

#	Author (Year)	Study design (Evidence Level*)	Participants	Multisensory environments	Outcome
5	Poza et al. (2013)	Randomized controlled trial (Level 1B)	Brain-injury	18-minute use **Visual:** bubble tubes, optic fibre, rotating mirror ball, projector, revolving disk showing moving pictures **Auditory**: stereo system for relaxing sound of nature	**Psychological Well-being** • Electroencephalographic (EEG) measure suggests a state of satisfaction and relaxation in the MSE group. • Significant differences between the intervention and control groups. • Significant increase in relative power for low-frequency bands and a significant decrease for fast rhythms.
6	Sánchez et al. (2016a)	Randomized controlled trial (Level 1B)	Dementia	30-minute use, twice weekly, for 16 weeks **MSE intervention group:** (non-directive approach):. **One-to-one activity group** (directive)	**Behavioural Changes** • MSE group: Significant improvement in the NPI and Bedford Alzheimer Nursing Severity Scale (BANS-S). • Both MSE and activity groups showed an improvement in the CMAI aggressive behaviour factor and total score. **Psychological Well-being** • No difference in three groups in CSDD **Others** • Better effects on neuropsychiatric symptoms and dementia severity in patients with severe dementia, measured by BANS-S.
7	Sánchez et al. (2016b)	Randomized controlled trial (Level 1B)	Dementia	30-minute use, twice weekly, for 16 weeks **MSE group** (non-directive approach) **Music intervention group**: preferred music in a quiet room.	**Behavioural Changes** • Both MSE and music groups: there was improvement during the intervention in CMAI total score, with no significant differences between the groups. **Psychological Well-being** • Better effects on anxiety symptoms, measured by Rating Anxiety in Dementia (RAID); and dementia severity, measured by BANS-S
Evidence Level 2					
8	Bodison and Parham (2018)	Systematic review (Level 2A)	Autism Spectrum (ASC); Attention-Deficit / Hyperactivity Disorder (ADHD)	**Tactile**: Massage and touch according to protocol developed by Silva et al. (2019) **Proprioceptive**: weighted vests with 10% of the body weight **Vestibular**: Slow linear swinging	**Behavioural Changes** • Massage – Improved self-regulatory behaviours, and tactile-seeking or – avoiding tendency. • Weighted vests – no significant effect • Slow linear swinging – no significant effect on on-task behaviours.

(*continued*).

Table 1. Continued.

#	Author (Year)	Study design (Evidence Level*)	Participants	Multisensory environments	Outcome
9	Sánchez et al. (2013)	Systematic review (Level 2A)	Dementia	MSE, multisensory behaviour therapy	**Behavioural Changes** • Positive effects on the behaviour in the short-term • A potential to increase meaningful communication, a higher communication spontaneity, and level of eye contact. • Significant improvements in verbal and nonverbal communication with caregivers. **Psychological Well-being** • Significant improvement in their level of depression (happiness, enjoyment, better mood, less sadness) at short term. Long-term effects were not evident. **Others** • Improved cognitive status, assessed by the Mini-Mental State Examination (MMSE) among mildly affected people with dementia. • Functional status: Greater independence in activities of daily living (ADLs) assessed with the Katz index and the Assessment of Motor and Process Skills (AMPS).
10	Basadonne et al. (2021)	Non-randomized experimental study (Level 2B)	Autism Spectrum Conditions (ASC)	30 min, once/week, 5 sessions Fully digitized MSE Interactive **visual** and **auditory** stimuli	**Behavioural Changes** Increased performance scores in sustained attention, selective attention, association, single inhibition, receptive communication, verbalization, and turn.
11	Johnston, Egermann, and Kearney (2022)	Non-randomized experimental study (Level 2B)	Autism Spectrum Conditions (ASC); Auditory hypersensitivity	3D audio group. Stereo audio group Auditory: alarm, baby, engine, fireworks, hair dryer, children fighting, children playing	**Psychological Well-being** Significant reduction in self-reported anxiety of those in the 3D audio group. Positive impact on those participants exposed to the 'children playing' stimulus in the 3D audio group with a decrease of self-reported anxiety of 50%, this was followed by the 'children fighting' stimulus which showed a 33.18% decrease.
12	Mills et al. (2023)	Non-randomized experimental study (Level 2B)	Intellectual disabilities; Autism Spectrum Conditions (ASC); and/or other disabilities	Virtual Reality MSE, where users can freely engage with items on their agenda and timeline. **Visual:** interactive light panels, light curtain, lava lamp **Auditory**: music **Tactile:** vibration and massage	**Behavioural Changes** • No significant differences in adaptive behaviour, measured by Adaptive Behavior Assessment System (ABAS-3) **Psychological Well-being** • No significant differences anxiety level, measured by Glasgow Anxiety Scale for People with ID (GAS-ID) • Improvement in depression, measured by Glasgow Depression Scale with learning disability (GDS-LD) • Improvement in sensory processing, measured by Adolescent Adult Sensory Profile (AASP) • No significant differences in wellbeing, measured by Personal Wellbeing Index – Intellectual Disability (PWI), 3rd edition

(*continued*).

Table 1. Continued.

#	Author (Year)	Study design (Evidence Level*)	Participants	Multisensory environments	Outcome
13	Unwin, Powell, and Jones (2022)	Non-randomized experimental study; analytical observation (Level 2B)	Autism Spectrum Conditions (ASC)	MSE, where child in active – or passive-sensory change conditions **Visual**: coloured LED lights, bubble tube, fibre optics, mirror ball **Auditory:** sound and light board **Tactile:** tactile wall, tactile boards	**Behavioural Changes** Increased attention, reduced repetitive motor behaviours, sensory behaviours, stereotyped speech and vocalizations. No significant effects on social behaviours. **Psychological Well-being** No significant effects on anxiety, positive affect, and arousal.
Evidence Level 3					
14	Abraha (2017)	Systematic review (Level 3A)	Dementia	**Visual:** light therapy **Auditory**: music listening, moving, playing musical instrument **Tactile**: massage therapy using touch and calming music **Olfactory**: aromatherapy using plant products or aromatic plant oil **MSE**: indoor/outdoor sensory garden, Snoezelen with music, aroma, bubble tubes, fibre optic, moving shapes projected walls.	**Behavioural Changes** • Aromatherapy – Improved agitated behaviours • Massage therapy – decreased agitated behaviours, cognitive decline, wandering, behavioural disturbances, psychological problems such as depression, and anxiety, and improve quality of life. • Light therapy – improved cognition, ADLs, sleep, challenging behaviours, and psychiatric disturbances • Multisensory – reduced verbal agitation, improved positive behaviours, measured by INTERACT. • Music – reducing behavioural symptoms, depression. **Psychological Well-being** • Snoezelen – improved mood, enjoying self and bored/inactive, cognition, physiological, communication.
15	Dorn, Hitch, and Stevenson (2020)	Retrospective cohort study (Level 3B)	Adult at mental health rehabilitation unit	**Visual**: lights, fibre optics, projector, 'star lamp **Auditory**: speakers **Tactile and proprioceptive**: weighted blankets, tactile toys, bean bag, massage chair, hand-held massage equipment **Vestibular**: glider chair **Olfactory**: oils, scented play doughs, demister **Gustatory**: different chewy, sour, and sweet	**Behavioural Changes** Overall reduced behavioural arousal (one case exception), measured by Sensory Modulation Consumer Self Rating Tool. No significant difference between genders and ages.
16	Prince et al. (2022)	Cohort study (Level 3B)	Dementia	MSE with open floor plan **Visual**: LED lighting, colours, uplift, evening, and daytime modes. **Auditory**: soothing, stimulating sound **Tactile:** furniture, varying materials and textures **Olfactory**: aroma **Vestibular:** rocking chair, glider chair	**Behavioural Changes** **Psychological Well-being** Behavioral and Psychological Symptoms of Dementia (BPSD) The number of observed BPSD episodes changed from 367 (17%) pre-test to 298 (10%) post-test over a 12-month time period.

(*continued*).

Table 1. Continued.

#	Author (Year)	Study design (Evidence Level*)	Participants	Multisensory environments	Outcome
14	Abraha (2017)	Systematic review (Level 3A)	Dementia	**Visual:** light therapy **Auditory**: music listening, moving, playing musical instrument **Tactile**: massage therapy using touch and calming music **Olfactory**: aromatherapy using plant products or aromatic plant oil **MSE**: indoor/outdoor sensory garden, Snoezelen with music, aroma, bubble tubes, fibre optic, moving shapes projected walls.	**Behavioural Changes** • Aromatherapy – Improved agitated behaviours • Massage therapy – decreased agitated behaviours, cognitive decline, wandering, behavioural disturbances, psychological problems such as depression, and anxiety, and improve quality of life. • Light therapy – improved cognition, ADLs, sleep, challenging behaviours, and psychiatric disturbances • Multisensory – reduced verbal agitation, improved positive behaviours, measured by INTERACT. • Music – reducing behavioural symptoms, depression. **Psychological Well-being** • Snoezelen – improved mood, enjoying self and bored/inactive, cognition, physiological, communication.
15	Dorn, Hitch, and Stevenson (2020)	Retrospective cohort study (Level 3B)	Adult at mental health rehabilitation unit	**Visual**: lights, fibre optics, projector, 'star lamp **Auditory**: iPod and speakers **Tactile and proprioceptive**: weighted blankets, tactile toys, bean bag, massage chair, hand-held massage equipment **Vestibular**: glider chair **Olfactory**: oils, scented play doughs, demister **Gustatory**: different chewy, sour, and sweet lollies	**Behavioural Changes** Overall reduced behavioural arousal (one case exception), measured by Sensory Modulation Consumer Self Rating Tool. No significant difference between genders and ages.
16	Prince et al. (2022)	Cohort study (Level 3B)	Dementia	MSE with open floor plan **Visual**: LED uplighting and lowlighting, colour based on relax mode, uplift, evening, and daytime modes. **Auditory**: soothing, stimulating sound, sound system recessed in the ceiling **Tactile:** furniture and interior materials with varying textures **Olfactory**: aroma **Vestibular:** rocking chair, glider chair	**Behavioural Changes** **Psychological Well-being** Behavioral and Psychological Symptoms of Dementia (BPSD) The number of observed BPSD episodes changed from 367 (17%) pre-test to 298 (10%) post-test over a 12-month time period.

(*continued*).

Table 1. Continued.

#	Author (Year)	Study design (Evidence Level*)	Participants	Multisensory environments	Outcome
Evidence Level 4					
18	Breslin et al. (2020)	Scoping review (Level 4)	Intellectual and developmental disabilities	MSE: Music, slow-moving visual projections, bubble tubes, vibrating elements, aromatic oils, and deep-pressure stimulation.	**Behavioural Changes** • Reduced frequency of aggression, self-injury, stereotype behaviours. Increased positive behaviours (e.g. focus, engagement, attention) • No change in behaviour state (e.g. activity, alertness). **Psychological Well-being** • Decreased psychological distress and discomfort
19	Clare et al. (2020)	Qualitative research (Level 4)	Dementia	Weekly music-based sessions with visual, auditory, and tactile component.	**Behavioural Changes** • Verbal and nonverbal communication, social interactional components and agency to develop over time. • Help develop mirroring and turn-taking and improve quality of life for people with communication impairment. • Increase nonverbal communication and connection.
20	Collier and Jakob (2017)	Qualitative research (Level 4)	Dementia	**Visual:** bubble tubes, optic fibres, projector, glitter ball, light, etc. **Auditory:** relaxation music, natural sound, classical music, bells, musical instruments **Tactile:** optic fibres, tactile balls, fabrics, soft toys, massage, vibrating cushion, etc. **Olfactory:** aroma diffuser, food, scented balls, air fresheners, smelling session **Gustatory:** fruit, tea, cake, drinks, etc. **Vestibular:** rocking chair, beanbag, etc. Personal-centred sensory approach. Integrating natural features, reminiscence and familiar objects. Accessible sensory areas	**Psychological Well-being** • Potential to improve the wellbeing of people with dementia at the later stage • Enjoyment and feel fulfilled • Enhance well-being, happy resident, happy staff
21	Kim and Park (2022)	Case report (Level 4)	Autism Spectrum Conditions (ASC)	3/week, 6 weeks **Visual:** LED spotlight, mirror ball, projector screen, bubble columns, switch box, fibre optics, infinity 3D wall panel, plasma ball **Auditory:** sound system (high/low frequency, high/low-speed alpha wave, fast/slow music), musical squares, experience painting, sound & light panel, plasma ball, hanging bar brass, percussion instrument set, vibro-acoustic water bed	**Behavioural Changes** Improvement in target behaviours (sucking fingers, glancing sideways, flapping hands, making nonspeech sounds, sucking thumb, putting something in the mouth).
22	Lo Buono et al. (2022)	Case report (Level 4)	Cerebral Palsy; Intellectual Disability	Total 12 MSE sessions (non-directed), each rehabilitative session was composed motor exercises centred on flexibility exercises and stretching out stiff muscles (50 min), sensorial and cognitive stimulations (60 min) **Visual**: relaxing images, bath with coloured balls, luminous swing, lamps **Auditory**: relaxing music and sound (e.g. streams, waterfalls) **Tactile**: water matress **Proprioceptive**: luminous swing, obstacle path	**Behavioural Changes** • Reduction in self-harm and motor stereotypes (hand flapping). • Improved sustained attention. • Improved Pediatric Functional Independence Measure (WeeFIM), and Vineland-II adaptive behaviour profile scores.

(*continued*).

Table 1. Continued.

#	Author (Year)	Study design (Evidence Level*)	Participants	Multisensory environments	Outcome
23	Lorusso and Bosch (2018)	Systematic review (Level 4)	Dementia	MSEs that incorporated at least three FF&E items including ergonomic vibroacoustic furniture, bubble tubes, colour-changing lighting solutions, music, and/or fibre optics.	**Behavioural Changes** • Overall improvement in positive behaviours, engagement • Reduction of problem behaviours (e.g. agitated, aggressive behaviour), and behavioural and psychological symptoms of dementia (BPSD) **Psychological Well-being** • Improvement in mood **Others** • Decrease in the mean heart rate. • No significant difference in cognition.
24	Lorusso et al. (2022)	Qualitative research (Level 4)	Dementia	MSE with LED colour-changing lights, bubble tubes, vibroacoustic furniture, music, and aromatherapy	**Behavioural Changes** • Improvement in positive behaviours (e.g. engagement) • Reduced agitation, disruptive behaviour, and aggression. **Psychological Well-being** • Increased happiness • Positive impact on both people with dementia and staff. • Staff-rated preferences – the aromatherapy, bubble tube, wall projectors, and LED fibre optics, Megapod, and vibroacoustic furniture. • Unexpected negative report – a heightened sensitivity (e.g. fireworks display on visual lighting equipment).
25	Park et al. (2020)	Qualitative research; analytical observation (Level 4)	Autism Spectrum Conditions (ASC); ADHD; and/or Intellectual disabilities	Sensory wellbeing hub, 30–50 min/session **Respite zone**: beanbag, weighted blanket, fidget wall, nature projection, lite-brite **Active zone**: sound wall, texture wall, rolling pins, pin wall, trampoline, spun chair, car wash **Sensory cocoon**: tensile fabric, media wall	**Psychological Well-being** Students used MSE for respite purposes **Others** • sensory-avoiding score associated with cocoon-zone usage. • Sensory-seeking scores correlated with bean bag usage. • Students with high sensory sensitivity scores used beanbag, weighted blanket, sensory cocoon, tensile fabric, media wall, and aqua doodle.
26	Schoen (2019)	Case report (Level 4)	Sensory Processing Differences	STAR Process, which integrate play, MSE therapy, and parent education. 50 min/each session, 3–5 times/week	**Behavioural Changes** • Improved play level, positive affect, joint attention, and novel use were observed some of the participants.
27	Dalton (2016)	Expert opinion (Level 5)	Autism Spectrum Conditions (ASC)	Calming sensory room Simplified, minimal interaction/cognitive load Controllability of sensory stimulus Extreme personalization, Reduce errors	**Psychological Well-being** Promote restoration and relaxation

Note. *The levels and strengths of evidence are adapted from Center for Evidence-Based Medicine (2009), and the American Occupational Therapy Association (2020).
Level 1A – Systematic review of homogeneous RCTs with or without meta-analysis;
Level 1B – Well-designed individual RCT (Not a pilot or feasibility study with a small sample size);
Level 2A – Systematic review of cohort studies or Level 2 and better studies;
Level 2B – Individual prospective cohort study, low-quality RCT (e.g. $<$ 80% follow-up or low number of participants; pilot and feasibility studies); ecological studies; and two-group, nonrandomized studies;
Level 3A – Systematic review of case-control studies or Leve 3 and better studies;
Level 3B – Individual retrospective case-control study; one-group, nonrandomized pre-posttest study; cohort studies;
Level 4 – Case series (and low-quality cohort and case-control study); Qualitative studies; Systematic review of Level 4 and better studies;
Level 5 – Expert opinion without explicit critical appraisal.

Table 2. Quality assessment-randomized controlled trials.

Randomized controlled trials	Maseda et al. (2014a)	Maseda et al. (2014b)	Maseda et al. (2018)	Poza et al. (2013)	Sánchez et al. (2016a)	Sánchez et al. (2016b)
1. Was true randomization used for assignment of participants to treatment groups?	Y	Y	Y	U	Y	Y
2. Was allocation to treatment groups concealed?	U	U	U	U	U	U
3. Were treatment groups similar at the baseline?	Y	Y	Y	Y	Y	Y
4. Were participants blind to treatment assignment?	U	U	U	U	U	U
5. Were those delivering the treatment blind to treatment assignment?	U	U	U	U	U	U
6. Were treatment groups treated identically other than the intervention of interest?	Y	Y	Y	Y	Y	Y
7. Were outcome assessors blind to treatment assignment?	U	U	U	U	U	U
8. Were outcomes measured in the same way for treatment groups?	Y	Y	Y	Y	Y	Y
9. Were outcomes measured in a reliable way?	U	Y	Y	Y	Y	Y
10. Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analysed?	Y	Y	Y	U	Y	Y
11. Were participants analysed in the groups to which they were randomized?	Y	Y	Y	Y	Y	Y
12. Was appropriate statistical analysis used?	Y	Y	Y	Y	Y	Y
13. Was the trial design appropriate and any deviations from the standard RCT design (individual randomization, parallel groups) accounted for in the conduct and analysis of the trial?	Y	Y	Y	Y	Y	Y
Overall Risk of Bias	**M**	**M**	**M**	**M**	**M**	**M**

Note. Y – yes, N – no, U – unclear, NA – not applicable.
Scoring for overall risk of bias assessment: L – low risk of bias (0–3 no or unclear); M – moderate risk of bias (4–6 no or unclear); H – high risk of bias (7–9 no or unclear).

Table 3. Quality assessment-quasi-experimental studies.

Quasi-experimental studies	Basadonne et al. (2021)	Johnston, Egermann, and Kearney (2022)	Mills et al. (2023)	Unwin, Powell, and Jones (2022)
1. Is it clear in the study what is the 'cause' and what is the 'effect' (i.e. there is no confusion about which variable comes first)?	Y	Y	Y	Y
2. Were the participants included in any comparisons similar?	NA	Y	NA	Y
3. Were the participants included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest?	NA	Y	NA	Y
4. Was there a control group?	N	Y	N	Y
5. Were there multiple measurements of the outcome both pre and post the intervention/exposure?	Y	Y	Y	Y
6. Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analysed?	Y	Y	Y	U
7. Were the outcomes of participants included in any comparisons measured in the same way?	Y	Y	NA	Y
8. Were outcomes measured in a reliable way?	U	U	Y	Y
9. Was appropriate statistical analysis used?	Y	Y	Y	Y
Overall Risk of Bias	**L**	**L**	**L**	**L**

Note. Y – yes, N – no, U – unclear, NA – not applicable.
Scoring for overall risk of bias assessment: L – low risk of bias (0–3 no or unclear); M – moderate risk of bias (4–6 no or unclear); H – high risk of bias (7–9 no or unclear).

2014a); although subsequent experiments did not consistently replicate this effect (Sánchez et al. 2016b). One retrospective cohort study using the Sensory Modulation Consumer Self Rating Tool (SMCSRT) found a decrease in arousal levels among adults in a mental health rehabilitation unit from pre – to post-MSE exposure, with only one exception case showing increased arousal (Dorn, Hitch, and Stevenson 2020).

Behavioural Response. MSE has shown promise in improving adaptive response among individuals with intellectual and developmental disabilities (IDD). Breslin et al. (2020) reported a reduction in aggression, self-injury, and stereotypy. Sensory interventions have been also effective in reducing repetitive motor behaviours, sensory behaviours, and stereotyped vocalizations in children with ASC (Unwin, Powell, and Jones 2022),

Table 4. Quality assessment-cohort studies.

Cohort Studies	Dorn, Hitch, and Stevenson (2020)	Prince et al. (2022)
1. Were the two groups similar and recruited from the same population?	NA	NA
2. Were the exposures measured similarly to assign people to both exposed and unexposed groups?	NA	NA
3. Was the exposure measured in a valid and reliable way?	U	Y
4. Were confounding factors identified?	U	U
5. Were strategies to deal with confounding factors stated?	U	U
6. Were the groups/participants free of the outcome at the start of the study (or at the moment of exposure)?	Y	U
7. Were the outcomes measured in a valid and reliable way?	Y	Y
8. Was the follow up time reported and sufficient to be long enough for outcomes to occur?	NA	Y
9. Was follow up complete, and if not, were the reasons to loss to follow up described and explored?	NA	Y
10. Were strategies to address incomplete follow up utilized?	NA	NA
11. Was appropriate statistical analysis used?	Y	Y
Overall Risk of Bias	**M**	**L**

Note. Y – yes, N – no, U – unclear, NA – not applicable.
Scoring for overall risk of bias assessment: L – low risk of bias (0–3 no or unclear); M – moderate risk of bias (4–6 no or unclear); H – high risk of bias (7–9 no or unclear).

Table 5. Quality assessment-case reports.

Case reports	Bauer et al. (2023)	Kim and Park (2022)	Lo Buono et al. (2022)	Sochoen (2019)
1. Were patient's demographic characteristics clearly described?	Y	Y	Y	Y
2. Was the patient's history clearly described and presented as a timeline?	Y	Y	Y	Y
3. Was the current clinical condition of the patient on presentation clearly described?	Y	Y	Y	Y
4. Were diagnostic tests or assessment methods and the results clearly described?	Y	Y	Y	Y
5. Was the intervention(s) or treatment procedure(s) clearly described?	Y	Y	Y	Y
6. Was the post-intervention clinical condition clearly described?	Y	Y	Y	Y
7. Were adverse events (harms) or unanticipated events identified and described?	U	N	U	U
8. Does the case report provide takeaway lessons?	Y	Y	Y	Y
Overall Risk of Bias	**L**	**L**	**L**	**L**

Note. Y – yes, N – no, U – unclear, NA – not applicable.
Scoring for overall risk of bias assessment: L – low risk of bias (0–3 no or unclear); M – moderate risk of bias (4–6 no or unclear); H – high risk of bias (7–9 no or unclear).

as well as in improving target behaviours such as finger-sucking and hand-flapping (Kim and Park 2022; Lo Buono et al. 2022).

Dementia-Related Behaviours. MSE has shown significant improvements in various measures among individuals with dementia. Lorusso and Bosch (2018) and Prince et al. (2022) noted improvement in the Behavioral and Psychological Symptoms of Dementia (BPSD) score after MSE exposure. Multiple RCTs showed that MSE led to significant enhancement in the Bedford Alzheimer Nursing Severity Scale (BANS-S) scores compared with control groups (Maseda et al. 2014a; Sánchez et al. 2016a, 2016b) and the Neuropsychiatric Inventory (NPI) (Sánchez et al. 2016a).

Positive Behaviours. The impact of MSE on positive behaviours is notable across various populations. Maseda et al. (2018, 2014b) conducted RCTs using the Interact scale and observed enhancements in speech, social interaction, attentiveness,

Table 6. Quality assessment-qualitative studies.

Qualitative studies	Clare et al. (2020)	Park et al. (2020)	Lorusso et al. (2022)	Collier and Jakob (2017)
1. Is there congruity between the stated philosophical perspective and the research methodology?	U	Y	U	Y
2. Is there congruity between the research methodology and the research question or objectives?	Y	Y	Y	Y
3. Is there congruity between the research methodology and the methods used to collect data?	Y	Y	Y	Y
4. Is there congruity between the research methodology and the representation and analysis of data?	Y	Y	Y	Y
5. Is there congruity between the research methodology and the interpretation of results?	Y	Y	Y	Y
6. Is there a statement locating the researcher culturally or theoretically?	Y	Y	Y	U
7. Is the influence of the researcher on the research, and vice – versa, addressed?	U	U	U	U
8. Are participants, and their voices, adequately represented?	Y	Y	Y	Y
9. Is the research ethical according to current criteria or, for recent studies, and is there evidence of ethical approval by an appropriate body?	Y	Y	Y	Y
10. Do the conclusions drawn in the research report flow from the analysis, or interpretation, of the data?	Y	Y	Y	Y
Overall Risk of Bias	**L**	**L**	**L**	**L**

Note. Y – yes, N – no, U – unclear, NA – not applicable.
Scoring for overall risk of bias assessment: L – low risk of bias (0–3 no or unclear); M – moderate risk of bias (4–6 no or unclear); H – high risk of bias (7–9 no or unclear).

Table 7. Quality assessment-text and opinion.

Text and opinion	Dalton (2016)
1. Is the source of the opinion clearly identified?	U
2. Does the source of opinion have standing in the field of expertise?	Y
3. Are the interests of the relevant population the central focus of the opinion?	Y
4. Does the opinion demonstrate a logically defended argument to support the conclusions drawn?	Y
5. Is there reference to the extant literature?	Y
6. Is any incongruence with the literature/sources logically defended?	U
Overall Risk of Bias	L

Note. Y – yes, N – no, U – unclear, NA – not applicable.
Scoring for overall risk of bias assessment: L – low risk of bias (0–3 no or unclear); M – moderate risk of bias (4–6 no or unclear); H – high risk of bias (7–9 no or unclear).

enjoyment, alertness, and relaxation following MSE sessions. Moreover, MSE also supports cognitive functions, such as sustained and selective attention, inhibition, and communication skills, helping develop mirroring and turn-taking behaviours (Basadonne et al. 2021; Clare et al. 2020; Lo Buono et al. 2022). Furthermore, MSE has been associated with promoting engagement and positive interactions (Lorusso et al. 2022; Lorusso and Bosch 2018).

Functional behaviours are also supported by MSE use. In individuals with IDD, MSE interventions have been linked to enhancements in Pediatric Functional Independence Measure (WeeFIM) and Vineland-II adaptive behaviour profile scores (Lo Buono et al. 2022). Among people with dementia, MSE has been associated with greater independence in activities of daily living (ADLs), as assessed by the Katz index and the Assessment of Motor and Process Skills (AMPS) (Sánchez et al. 2013), and the Barthel index (Maseda et al. 2014a).

Additionally, Qigong sensory treatment (QST) demonstrates support of self-regulatory behaviours and tactile-seeking or – avoiding tendency among children with ASC (Bodison and Parham 2018), and positive behaviours such as focus, engagement, and attention, among individuals with IDD in clinical settings (Breslin et al. 2020).

Physical and psychological well-being

Depression and Anxiety. Multiple studies have highlighted the positive impact of MSE on depression and anxiety. Helbling, Grandjean, and Srinivasan (2023) revealed a significant effect of MSE on depression. Similarly, Sánchez et al. (2013) and Mills et al. (2023) found that MSE led to a significant improvement in depression levels, as assessed by the Geriatric Depression Scale (GDS). Two RCTs also showed improvement in the Cornell Scale for Depression in Dementia (CSDD) scores, although the results were not statistically significant (Maseda et al. 2014a; Sánchez et al. 2016b). Regarding anxiety, a significant group-time interaction was noted in the Rating Anxiety in Dementia (RAID) scores from pre – to post-MSE (Sánchez et al. 2016b).

Mood. MSE has been associated with positive effects on mood. Breslin et al. (2020) have reported decreased psychological distress and discomfort. Individuals with dementia perceived MSE as beneficial, leading to potential improvements in well-being for both residents and staff (Collier and Jakob 2017). Deep touch pressure via weighted wraps resulted in a significantly reduced sensory discomfort (Bodison and Parham 2018). The use of spatial audio stimulations was linked with significant reductions in negative emotional reactions among autistic children experiencing auditory hypersensitivity (Johnston, Egermann, and Kearney 2022).

Wellbeing and Quality of Life. MSE has shown mixed effects of MSE on quality of life (QoL). There was no significant on the self-reported QoL measures in adults with cognitive impairment (Helbling, Grandjean, and Srinivasan 2023); however, there were biometric parameters that suggest an increase in users' physical and psychological well-being. Specifically, the heart rate was significantly lower when exposed to MSE (Helbling, Grandjean, and Srinivasan 2023; Maseda et al. 2018; Maseda et al., 2014b). Furthermore, there was a consistent increase in the mean values of oxygen saturation (SpO_2) (Maseda et al. 2018, 2014b). One additional RCT using electroencephalographic (EEG) measures, suggests a state of satisfaction and relaxation (Poza et al. 2013).

Multisensory environment design and user experiences

This section describes the multisensory environment design considerations by explaining the characteristics of sensory stimuli and users' sensory experiences (Aim #2). Findings highlight MSE design strategies with key themes based on the SIT. Table 9 summarizes the overall findings.

Sight

Sight is a visual sense that perceives and detects light and objects through human eyes. The majority of studies included visual elements, such as fibre optics, bubble tubes, water columns, screen projectors, mirrors, rotating mirror balls, revolving disks, motion graphics, and LED lights. MSE provides users with a range of visual variations in colours, light levels, shapes, patterns, depth, and motion dynamics.

Calming effects were created by providing stationary movement mode, or turn-off options, which is associated with the state of relaxation measured by EEG brain activity (Poza et al. 2013). Stimulating environments can be created by operating multiple stimuli at the same time, playing motion graphics with faster movement, or choosing revolving modes. These design strategies positively impact in reducing visual-seeking tendency (Kim and Park 2022; Park et al. 2020; Poza et al. 2013).

Hearing

Hearing refers to the perception and processing of sound. Auditory stimuli were controlled in the included studies using sound systems, vibroacoustic equipment, interactive devices, white noise machines, and environmental soundscapes. Different strategies were used in previous studies; for example, different types of music (e.g. rap, pop, classic, etc.), sounds (e.g. alarm, engine, hairdryer, etc.), natural sounds (e.g. birds chirping), preferred music in a quiet room.

Auditory sensory can vary by volume(decibel), beat, tempo, pitch, and spatial sound effects. Background sound in the built environment such as upbeat, lively music with high volume, high frequency (432–528 Hz), and fast-paced rhythms (110–160 bpm) create stimulating environments. Meanwhile, the opposite settings – low frequency (8–9 Hz), and low speed alpha wave sounds (60–80 bpm) – can create relaxation and calmness. Integrating elements of nature contributes to calming effects

Table 8. Quality assessment-systematic review.

Systematic review	Abraha (2017)	Bodison and Parham (2018)	Breslin et al. (2020)	Helbling, Grandjean, and Srinivasan (2023)	Lorusso and Bosch (2018)	Sánchez et al. (2013)
1. Is the review question clearly and explicitly stated?	Y	Y	Y	Y	Y	Y
2. Were the inclusion criteria appropriate for the review question?	Y	Y	Y	Y	Y	Y
3. Was the search strategy appropriate?	Y	Y	Y	Y	Y	Y
4. Were the sources and resources used to search for studies adequate?	Y	Y	Y	Y	Y	Y
5. Were the criteria for appraising studies appropriate?	Y	Y	U	Y	Y	U
6. Was critical appraisal conducted by two or more reviewers independently?	Y	Y	Y	Y	U	U
7. Were there methods to minimize errors in data extraction?	Y	Y	U	Y	U	Y
8. Were the methods used to combine studies appropriate?	Y	U	Y	Y	Y	Y
9. Was the likelihood of publication bias assessed?	U	U	U	Y	U	U
10. Were recommendations for policy and/or practice supported by the reported data?	Y	Y	Y	Y	Y	Y
11. Were the specific directives for new research appropriate?	Y	Y	Y	Y	Y	Y
Overall Risk of Bias	**L**	**L**	**L**	**L**	**L**	**L**

Note. Y – yes, N – no, U – unclear, NA – not applicable.
Scoring for overall risk of bias assessment: L – low risk of bias (0–3 no or unclear); M – moderate risk of bias (4–6 no or unclear); H – high risk of bias (7–9 no or unclear).

(Collier and Jakob 2017; Poza et al. 2013). The use of spatial audio technology in the built environment was effective in significantly reducing negative emotional reactions among autistic children experiencing auditory hypersensitivity (Johnston, Egermann, and Kearney 2022).

Touch

The sense of touch is a tactile perception that comes through the skin and deeper tissues of the human body. The included studies provided feelings of pressure, temperature, texture, and vibration. Different tactile inputs within the built environment can be from tactile wall panels, boards, vibrating furniture, as well as integrating a wide range of textures and materials like water, sand, and natural surfaces. In an observation study with self-exploratory MSE, students with ASC tend to frequently use the beanbag, weighted blanket, and a space surrounded by tensile fabric (Park et al. 2020). Massage therapy significantly helped regulating aggression and self-injury behaviours among adults with cognitive impairment (Helbling, Grandjean, and Srinivasan 2023).

Smell

The sense of smell is the perception of scents. MSE used aroma diffusers, scented materials, and accessories. The sensory exposure was regulated by scent intensity and delivery duration. Though the majority of the included studies employed olfactory stimuli as aroma therapy, there were no specific studies that directly investigated its impact on users' experiences.

Taste

The gustatory sense, known as taste, is a sense that distinguishes the flavour of substances put into through mouths. Different types of flavours, textures, and temperatures can stimulate different taste receptors. Only two studies used gustatory stimuli in MSEs (Collier and Jakob 2017; Dorn, Hitch, and Stevenson 2020). Understandably, not many studies did not integrate gustatory senses as they involve hygiene and safety concerns.

Body movement

Body movement is about a sense of balance, spatial orientation, and movements, perceived by a vestibular system located within the inner ears. MSE provided the vestibular sensory input using different types of seating (e.g. rocking chairs, stability balls, or spun chairs), as well as balance equipment, and different types of swings (e.g. flatform, hammocks, bolster swings). These furniture's or equipment' size and motion adjustability can contribute to controlling the amount of vestibular sensory input. Slow linear swinging and different types of seating in the built environment are considered to promote attention and on-task behaviours by reducing arousal levels (Bodison and Parham 2018); however, no sufficient evidence was found in the included literature.

Body awareness

Body awareness, also known as proprioception, is a sense that detects the position and movement of body parts; for example, when we are in a certain position, we perceive changes in muscle length and tension and joint angle and position. Proprioceptive input can be from pressure-sensitive cushions and furniture (e.g. hugging pod, squeeze seat), weighted equipment

Table 9. Evidence-based multisensory environment (MSE) design strategies.

Sensory Type	Design Strategies	Helbling, Grandjean, and Srinivasan (2023)*	Maseda et al. (2014a)	Maseda et al. (2014b)	Maseda et al. (2018)	Poza et al. (2013)	Sánchez et al. (2016a)	Sánchez et al. (2016b)	Bodison and Parham (2018)*	Sánchez et al. (2013)*	Basadonne et al. (2021)	Johnston, Egermann, and Kearney (2022)	Mills et al. (2023)	Unwin, Powell, and Jones (2022)	Abraha (2017)*	Dorn, Hitch, and Stevenson (2020)	Prince et al. (2022)	Bauer et al. (2023)	Breslin et al. (2020)*	Clare et al. (2020)	Collier and Jakob (2017)	Kim and Park (2022)	Lo Buono et al. (2022)	Lorusso and Bosch (2018)*	Lorusso et al. (2022)	Park et al. (2020)	Schoen (2019)	Dalton (2016)
Evidence level		1A	1B						2A			2B			3A	3B	4											5
Participants		1	2	3	2	4	2	2	5,6	2	5	5,6	5,7	5	2	8	2	5,7	7	2	2	5	5,7	2	2	5,6,7	3	5
Sight	• Variations in colours, light, shapes, patterns, depth, and motion.	O	O	O	O	O	O	O			O		O	O	O	O	O	O		O	B	O			O	O		
Hearing	• Variations in beat, tempo, pitch, and types of instruments.	O	O	O	O	O	O	O			O	*P*	O	O	O	O	O	O		O	B	O			O	O		
Touch	• Massage therapies • Variations in feeling of pressure, temperature, texture, and vibration.	O	O	O	O		O	O	B				O	O	O	O	O	O		O	O	O				O	O	
Smell	• Aroma therapy Variations in sent intensity and duration	O	O	O	O		O	O							O	O	O					O			O			
Taste	• Variations in flavours, textures, temperature.															O												
Body movement	• Variations in equipment' size and motion adjustability								B								O					O				O	O	
Body awareness	• Weighted vest, blanket • Variations in deep pressure								B							O						O				O	O	
Multi-sensory	**Customizable Sensory Input** • Flexibility • calming/stimulating modes		B	B*P*	O	*P*	O	O									O		O		B	O				O		O
	Non-directive approach • non-sequential approach		B	B*P*	O		O	O					O	B		B					B					O		
	Interactive design • Visual sound feedback based on users' movement										B		O				O	O			B							
	Use of technology • VR, AR • Fully digitalized MSE										O		*P*				O	O										
	Reported MSE size • Vary ranging from 12 m^2 – 42m^2(physical), 9m^2 (AR)					O					O			O				O										
	Reported sensory room usage • Vary ranging 5–50 min, repetitive use		O	O	O	O	O	O			O			O				O		O							O	

Note. Strengths of evidence (American Occupational Therapy Association 2020; Center for Evidence-Based Medicine 2009): Strong – two or more Level 1 studies; Moderate – at least one Level 1A or Level 1B high-quality study or multiple moderate-quality studies (Level 2A/B, Level 3A/B, etc.); Low – small number of low-level studies, flaws in the studies.
* indicates review studies.
Outcome classification: 'O' – design strategies implemented/ or suggested by the studies, 'B' – design strategies associated with behavioural changes, '*P*' – design strategies associated with physical and psychological well-being.
Participants classification: '1' – People with cognitive impairment, '2' – People with dementia, '3' – People with sensory processing differences, '4' – People with brain injury, '5' – Autism Spectrum Conditions (ASC), or Cerebral Palsy, '6' – Attention Deficit / Hyperactivity Disorder (ADHD), '7' – Intellectual and/or developmental disabilities, '8' – Adults in a mental health rehabilitation unit.

(such as weighted vests, blankets, and lap pads), climbing structures in built environments, and activities like stretches can help simulate these senses and allow users to recognize their body parts and their postures. Weighted vest interventions were associated with improved in-seat behaviour and attention in children with ADHD compared to the control group during classroom activities (Bodison and Parham 2018).

Discussion

Multisensory design implications

This study investigated MSEs for people with sensory processing differences including sight, hearing, touch, smell, taste, body movement, and body awareness. Reviewing the literature, this study further translates existing evidence into design strategies that can be implemented in the built environment. The following section list MSE design implications responsive to the diverse sensory needs (Aim #3).

1. Customizable Sensory Input: Provide customizable sensory inputs to accommodate individual preferences. Previous studies emphasized the importance of offering diverse sensory experiences (Breslin et al. 2020; Dalton 2016). Space design with adjustable sensory inputs, like dimmable lights and sound controls, can switch between stimulating and calming modes. Such sensory experiences influence relaxation, as reflected in EEG results among people with brain injuries (Poza et al. 2013).

Built environments with customizable sensory stimuli support individuals with SOR or SUR (Kim and Park 2022). For instance, visually and auditorily stimulating MSEs positively impact sensory-seeking tendency of children with hypo-visual and hypo-auditory sensitivity (Kim and Park 2022). Different seating options that allow body movement support attention and on-task behaviours in students with ASC and/or ADHD (Bodison and Parham 2018). In addition, natural features in the built environments contribute to calming effects, which align with biophilic design and stress reduction theory (Ryan and Browning 2020; Ulrich et al. 1991).

2. Non-directive approach: **Engage users to explore and interact with their sensory environment in a self-directed manner.** It is crucial to offer users independent sensory exploration, interaction, and engagement, even when under the supervision of care providers (Basadonne et al. 2021; Collier and Jakob 2017). Included studies often applied a non-directive approach, which encouraged users to choose and control sensory stimuli of their choice in non-sequential and un-patterned ways. Integrating touch-sensitive materials, finishes, and lighting, in the built environment can support users with engaging with sensory stimuli at their own pace. These space design strategies are related to positive behaviours and psychological well-being among people with dementia (Maseda et al. 2014a, 2014b); reduced arousal level among adults in a mental health rehabilitation unit (Dorn, Hitch, and Stevenson 2020), and increased attention in children with ASC (Unwin, Powell, and Jones 2022). This approach aligns with control theory which posit the sense of control over individuals' environment is crucial for human well-being (Averill 1973).

3. Interactive Design and Technology: Use technology to create interactive and responsive environments. The design considers visual, sound, and tactile feedback mechanisms that respond to user movement. For example, integrating motion sensors in the built environment can trigger changes in lighting, sound, or visual displays based on the user's movements. This responsiveness enhances the sense of agency, engagement, and control (Basadonne et al. 2021). User-friendly, intuitive controls empower users to influence their environment and shape their experience according to their preferences (Dalton 2016).

Technology is further advancing interactive multisensory experiences. The fully digitalized MSE has supported increased performance in sustained attention, selective attention, association, inhibition, receptive communication, verbalization among adolescents and adults with ASC (Basadonne et al. 2021). The use of augmented reality (AR) and virtual reality (VR) also demonstrated their impact on psychological well-being of people with ID, ASC, and/or learning disabilities (Bauer et al. 2023; Mills et al. 2023).

4. Appropriate size and usage: Design adequate size and usage to support various activities and purposes. The size of MSE used in previous studies ranged from 12–42 m^2 for physical MSE and 9 m^2 for AR MSE (Bauer et al. 2023). Built environments intended for active sensory exploration (e.g. children with ASC, ADHD) require ample space for movement and dynamic activities, while spaces for relaxation (e.g. individuals with dementia) may benefit from a contained, intimate setting.

Repetitive uses contributed to users' outcomes, with encouraged weekly-basis usage (Clare et al. 2020); for instance, MSE use varied from 5 to 50 min/each usage, 1–5 times/week across the included studies. In a therapeutic setting, usage can be guided by therapists and therapeutic goals. Schools or care facilities should integrate MSEs into the routines to provide continuous sensory support.

Gap and future study

Several gaps exist in the current body of research. One gap is the lack of studies on the long-term impact of MSEs as most research focuses on the short-term outcomes. Future studies are necessary to explore how repeated exposure to MSEs influences users' behaviour and well-being over time. Also, safety features, such as soft surfaces and stability, though not directly related to the users' behavioural or psychological outcomes, are crucial for designing MSEs and support user's self-exploration. Future study can also consider quantitative measures to accurately assess the sensory inputs and user responses. Technology integration, including VR and AR, is also an area with significant potential (Yi et al. 2024; Yi and Bhattachaarjee 2023). Further research is needed to fully understand their benefits. Lastly, the tools available for measuring the level and strength of evidence are primarily grounded in medical models, such as AOTA. While useful for accessing therapeutic outcomes, these tools may not fully capture subjective experiences based on neurodivergent paradigm.

Neurodiversity paradigm and MSEs

This study viewed MSE users with neurodiversity paradigm, which offers a perspective to see individuals with sensory processing differences from both medical and social models. The medical model frames neurological and sensory differences as dysfunctions requiring treatment; meanwhile, the social model views such differences as the result of interaction between individuals and environments (Shakespeare 2006). The majority of articles reviewed indicate that MSEs were initially developed with the medical model, primarily as a therapeutic interventions to help sensory integration (Ayres 1972). These studies provide insights into design and use of MSEs in the healthcare settings.

While acknowledging the foundational role of medical model in guiding MSE design, this study also incorporates the neurodiversity paradigm, recognizing that MSEs can serve as supportive environments for individuals across various sensory spectrums. With this broader perspective, designers can leverage the evidence-based MSE design strategies to create sensory environments that accommodate diverse needs of neurodivergent individuals.

Conclusion

The evidence supports that MSE can contribute to positive behaviours and physical, and psychological well-being across diverse populations. MSE helps attention, engagement, interactions, and independence in ADLs. while reducing agitation, aggression, self-injury, arousal, and stereotype behaviours. MSEs also support emotional status and relaxation while decreasing distress, anxiety, and depression.

The findings were prescribed into evidence-based MSE design strategies, which considered different sensory modulations and emerging themes: customizability, non-directive approach, interactive design, technology, appropriate size, and usage. These identified MSE design strategies guide designers with evidence-based approaches that accommodate neurodivergent people's varying sensory needs. However, some design considerations rely on moderate or low evidence, showing the need of future study to further validate it (AOTA 2020; CEBM 2009). Previous studies often used different conceptual frameworks or did not provide sufficient details of MSE design, influencing the content and quality of evidence. Future studies that sophisticatedly quantify and measure sensory parameters will expand the understanding of human-sensory environment interactions.

The evidence-based MSE design strategies started from the extreme users' sensory needs; however, it is desirable to apply these principles with a universal design approach (Heylighen, Van der Linden, and Van Steenwinkel 2017). Well-designed MSEs have promising potential to provide sensory support that aligns with neurodivergent individuals' preferences and needs. MSEs can enhance their quality of life by promoting meaningful participation in activities that may otherwise be inaccessible. Indirect societal benefits will extend to supporting neurodivergent individuals' integration into regular classrooms, the workforce, and public access, therefore embracing diversity.

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Data availability statement

The data used and/or analysed during the current systematic review are available from the corresponding author on reasonable request.

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