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Environmental Enrichment for Early Stroke Rehabilitation: A Systematic Review

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Abstract

Stroke remains a leading cause of long-term disability, and the first 12 weeks after stroke represent a period of heightened neuroplasticity during which activity-dependent stimulation may support neurological recovery. Environmental enrichment (EE) has been proposed as a potentially low-cost strategy to increase meaningful physical, cognitive, and social engagement beyond scheduled rehabilitation sessions. However, evidence regarding its effectiveness in early stroke rehabilitation has remained limited. This systematic review aimed to identify, critically appraise, and synthesize comparative evidence on EE during early inpatient stroke rehabilitation, focusing on activity levels, safety, functional recovery, and psychological well-being, while evaluating methodological quality and risk of bias. Four databases—PubMed, ScienceDirect, Europe PMC, and Epistemonikos—were searched, yielding 492 records. Following screening, two nonrandomized controlled studies met the inclusion criteria. Methodological quality was appraised using Oxford Centre for Evidence-Based Medicine (OCEBM) critical appraisal worksheets, risk of bias was assessed using the Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) tool, and certainty of evidence was evaluated qualitatively according to the Grading of Recommendations Assessment, Development and Evaluation (GRADE) framework. Both studies reported increased overall, physical, and social activity and reduced inactivity following EE interventions. Improvements appeared greater in acute stroke settings than in subacute rehabilitation, where limited fidelity to individually tailored enrichment protocols may have attenuated intervention effects. Neither study identified an increased risk of adverse events, and one reported fewer adverse events and a shorter hospital length of stay. Neither study demonstrated statistically significant improvements in functional outcomes or quality of life at three months. Overall risk of bias was rated serious in one study and moderate in the other, while certainty of evidence ranged from low to very low across the assessed outcomes. These findings suggested that EE may be a feasible and potentially low-cost adjunct to early inpatient stroke rehabilitation, with benefits for daily activity and engagement. However, the limited evidence did not establish its long-term effectiveness in improving functional recovery or reducing disability.

INTRODUCTION

Stroke remains a leading cause of mortality and long-term disability worldwide, and improvements in survival following acute stroke have increased the demand for inpatient rehabilitation services addressing its physical, cognitive, and psychosocial consequences (Carey et al., 2020; Jones et al., 2020). As stroke care systems continue to expand, ensuring access to effective inpatient rehabilitation during the early stages of recovery has become an important clinical priority.

Stroke rehabilitation research has traditionally emphasized the intensity and content of structured, individualized therapy sessions. However, observational studies have consistently reported that stroke survivors spend much of their waking time inactive outside scheduled rehabilitation sessions (Deziel et al., 2020; Linares et al., 2020; Rodriguez Santana et al., 2020). This is particularly relevant during the first 12 weeks after stroke, a period associated with heightened neuroplasticity and increased responsiveness to activity-dependent rehabilitation interventions (Conti et al., 2022; Dimitrova et al., 2021; Moon, 2021). Environmental enrichment (EE), an approach initially investigated in animal models and subsequently adapted for inpatient rehabilitation settings, has been proposed as a potentially low-cost strategy to increase physical, cognitive, and social engagement beyond scheduled therapy sessions. EE interventions typically provide structured access to individual and communal activities, including games, reading materials, and opportunities for social interaction (Fatima et al., 2021; Gianquintieri & Caiani, 2025; Simon et al., 2026). Early nonrandomized studies conducted in stroke rehabilitation units reported increased patient activity and reduced time spent inactive or alone following the introduction of EE interventions (Dal et al., 2023; Deziel et al., 2022; Spoden et al., 2022).

Despite these promising findings, important gaps remain in the available evidence. Standardized protocols for implementing EE in inpatient stroke rehabilitation have not been established, and intervention delivery varies across healthcare settings, ward environments, and staffing arrangements (Hart et al., 2023; Ventura et al., 2021; Wenzel & Risley, 2021). Furthermore, existing comparative studies have predominantly employed nonrandomized designs, raising concerns about potential confounding, differential attrition, and inconsistent intervention fidelity (Bae, 2024; Enea et al., 2024; Nwanosike et al., 2025). These methodological limitations highlight the need for structured risk-of-bias assessments alongside evaluations of clinical outcomes. A systematic synthesis integrating intervention outcomes with methodological quality and certainty-of-evidence assessments is therefore warranted.

This systematic review aimed to identify, critically appraise, and synthesize comparative evidence on EE during early inpatient stroke rehabilitation, focusing on patient activity levels, safety, functional recovery, and psychological well-being compared with usual ward-based care. The review also assessed the methodological quality and risk of bias of eligible studies to determine the certainty of the available evidence and identify limitations affecting the interpretation of reported outcomes.

The review included comparative studies involving adults aged 18 years or older who received inpatient rehabilitation during the acute or early subacute phase, defined as the first three months after stroke onset. Eligible studies compared structured EE interventions with usual ward-based rehabilitation and reported relevant clinical, behavioral, or functional

outcomes. Both randomized controlled trials and nonrandomized comparative studies were eligible for inclusion. Studies conducted exclusively in animal models, studies involving mixed neurological populations without separately reported stroke-specific findings, and publications without accessible peer-reviewed full-text reports were excluded.

METHOD

Protocol

This review followed PRISMA 2020 guidance for search, selection, and reporting. It was not prospectively registered; this is acknowledged as a limitation (Section 4.5)

Eligibility Criteria

Included: (1) adults (≥18 years) with clinically diagnosed stroke; (2) acute to early subacute phase (0 days–3 months post-stroke); (3) EE compared with usual/standard care; (4) clinical or functional outcomes reported; (5) Randomized controlled trials, cohort, case-control, or quasi-experimental studies (including non-randomized controlled/cluster trials and controlled before–after designs); (6) full text in English/Indonesian within 20 years.

Excluded: animal studies; mixed neurological populations without stroke-specific data; and conference abstracts, protocols without results, editorials, or opinions.

Information Sources and Search Strategy

Four databases PubMed, ScienceDirect, EuropePMC, and Epistemonikos were searched using "stroke," "inpatient," and "environmental enrichment," combined with Boolean operators and MeSH/title-abstract fields, yielding 492 records (PubMed n=48, Europe PMC n=270, ScienceDirect n=96, Epistemonikos n=78). Full Boolean search strings per database are reported in Appendix B (Table B1).

Study Selection

Records were de-duplicated, then screened by title/abstract and full text against the eligibility criteria; eligible studies underwent formal critical appraisal (Figure 1)

Data Extraction

Data extracted per study: design, setting, sample size, participant characteristics, intervention/comparator components, outcomes, effect estimates, and adverse events.

Critical Appraisal, Risk of Bias, and Certainty of Evidence

Validity, importance, and applicability were appraised using OCEBM worksheets (RAMMBO framework) and classified per OCEBM 2011 Levels of Evidence. As both included studies were nonrandomized controlled (before–after) intervention studies, risk of bias was formally assessed using ROBINS-I the appropriate tool for this design across its seven domains (confounding, selection of participants, classification of interventions, deviations from intended interventions, missing data, measurement of outcomes, and selection of the reported result). Each domain was rated Low, Moderate, Serious, Critical, or No information, with the overall judgement taken as the most severe domain rating. Detailed domain-level justification, including supporting quotations from the source articles, is reported in Appendix A. Certainty of evidence per outcome was rated qualitatively (high/moderate/low/very low), considering risk of bias, consistency of effect, and precision, consistent with GRADE principles.

RESULTS AND DISCUSSION

Study Selection

Of 492 records identified (PubMed n=48, Europe PMC n=270, ScienceDirect n=96, Epistemonikos n=78), 157 duplicates were removed, leaving 335 for title/abstract screening. After excluding 325 records, 10 full-text articles were assessed; eight were excluded (non-human design, n=4; inappropriate design, n=4). Two nonrandomized controlled studies were included (Figure 1).



Figure 1. PRISMA 2020 flow diagram of study identification, screening, and inclusion.

Characteristics of Included Studies

Both studies compared an EE programme with usual ward-based care but differed in design, setting, and rehabilitation phase (Table 1): Janssen et al. conducted a four-site nonrandomized cluster trial in subacute rehabilitation; Rosbergen et al. conducted a single-centre controlled before–after study in an acute stroke unit.

Table 1. Characteristics of Included Studies

Item	Janssen et al. (2022) – AREISSA trial	Rosbergen et al. (2017)
Design / OCEBM level	Nonrandomized cluster trial (Phase II); Level 3b (non-randomised controlled cohort/follow-up study)	Controlled before–after pilot study; Level 3b (non-randomised controlled cohort/follow-up study)
Setting	4 metropolitan rehabilitation units, Australia; mean throughput 129 strokes/year; PT ratio ~1:8	Single acute stroke unit, regional Australian hospital (Nambour, Sunshine Coast)
Participants	n=193 recruited (173 analyzed for activity; 139 at 3 months); control n=102, experimental n=91	n=62 recruited (30/group analyzed); plus n=31 sustainability group
Intervention vs comparator	Communal enrichment (gaming, internet, reading, puzzles, dining area) plus individual satchel (music, audiobooks, hobbies) vs usual care	Communal equipment (iPads, books, games, music), daily group sessions, communal meals vs usual care

Item	Janssen et al. (2022) – AREISSA trial	Rosbergen et al. (2017)
Outcomes measured	Behaviourally-mapped activity; mRS, RMI, MoCA, HADS, self-efficacy, fatigue, ACS, AQoL-6D; safety	Behaviourally-mapped activity; Modified Barthel Index, mRS, 10m walk, HADS, EQ-5D-3L VAS; adverse events, length of stay

ACS, Activity Card Sort; AQoL-6D, Assessment of Quality of Life 6-Dimension; AREISSA, Altering the Rehabilitation Environment to Improve Stroke Survivor Activity; EQ-5D-3L VAS, EuroQol 5-Dimension 3-Level Visual Analogue Scale; HADS, Hospital Anxiety and Depression Scale; mRS, modified Rankin Scale; MoCA, Montreal Cognitive Assessment; OCEBM, Oxford Centre for Evidence-Based Medicine; PT, physical therapist; RMI, Rivermead Mobility Index.

Recruitment dates, trial registration/ethics approvals, sample-size basis, and funding sources for both studies are reported in Appendix D (Table D1).

Risk of Bias Assessment (ROBINS-I)

Both included studies were nonrandomized, controlled, before–after intervention studies; the Cochrane RoB 2.0 tool (for randomized trials) was therefore not applicable, and risk of bias was assessed using ROBINS-I. Janssen et al. was judged at overall Serious risk of bias, driven principally by uncontrolled secular confounding across a four-year recruitment period, poor fidelity of the individually tailored enrichment component (accessible within reach only 24% of the time), and high, differential three-month attrition (37% experimental vs 16% control); outcome measurement and reported-result selection were nonetheless Low risk, reflecting blinded assessors and prospective registration.

Rosbergen et al. was judged at overall Moderate risk of bias. Baseline characteristics were well balanced (P>0.063 for all variables) and missing data were minimal and non-differential, but the nonrandomized before–after design, unblinded treating staff, imperfect group-session fidelity (78% delivered as intended), and a self-acknowledged Hawthorne-type observation effect precluded a Low-risk rating. Domain-level judgements for both studies, with supporting justification and quotations from the source articles, are reported in Appendix A and summarized in Table 2 and Figure 2.

Table 2. ROBINS-I Risk of Bias Summary

Domain	Janssen et al. (2022)	Rosbergen et al. (2017)
D1. Confounding	**Serious**	**Moderate**
D2. Selection of participants into the study	**Moderate**	**Low**
D3. Classification of interventions	**Low**	**Low**
D4. Deviations from intended interventions	**Serious**	**Moderate**
D5. Missing data	**Serious**	**Low**
D6. Measurement of outcomes	**Low**	**Moderate**
D7. Selection of the reported result	**Low**	**Low**
Overall risk of bias	**Serious**	**Moderate**

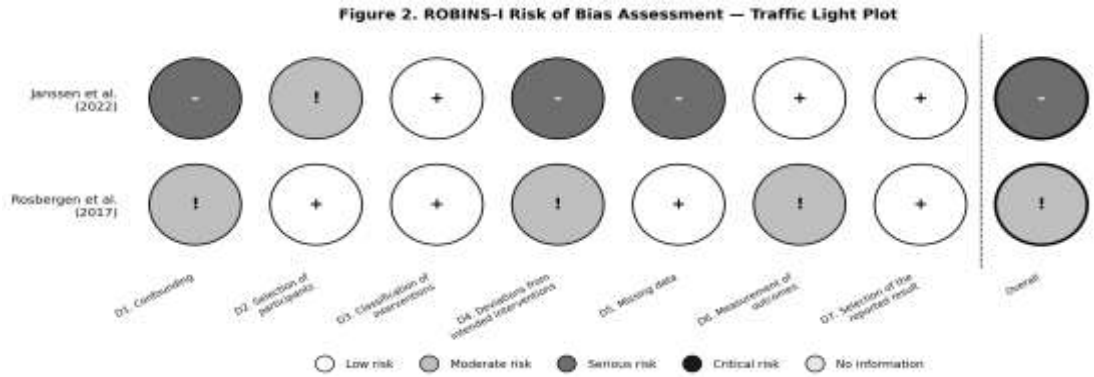


Figure 2. ROBINS-I traffic-light plot of domain-level and overall risk-of-bias judgements for the two included studies.

Effects of the Intervention

Both studies found EE increased overall, physical, and social activity relative to usual care, though the magnitude differed borderline-to-modest in Janssen et al. (consistent with the poor fidelity of individual enrichment noted under D4) versus large and consistent in Rosbergen et al.; effects on cognitive activity were discordant between studies. Neither study identified a safety signal against EE: both found no between-group difference in serious adverse events, and Rosbergen et al. additionally found fewer overall adverse events and a shorter length of stay with EE, sustained at six months. Neither study demonstrated a significant functional or quality-of-life benefit at three months, with only a nonsignificant mobility trend observed in Janssen et al. Detailed effect estimates (with 95% confidence intervals and P-values) for all activity, safety, and functional/quality-of-life outcomes are reported in Appendix C (Table C1).

Summary of Findings and Certainty of Evidence

Certainty of evidence was low to very low across all outcome domains, reflecting the nonrandomized designs, the Serious (Janssen et al.) and Moderate (Rosbergen et al.) overall ROBINS-I ratings, and the small evidence base of only two studies (Table 4). The number of participants analyzed varies by outcome domain, as noted below; the two studies contributed a combined 255 participants at recruitment (193 + 62), of whom 233 were analyzed for activity outcomes and 199 for three-month functional/quality-of-life outcomes.

Table 3. Summary of Findings and Certainty of Evidence

Outcome	Findings across studies	Studies (N analyzed)	Certainty
Overall / physical activity	Consistent benefit favouring EE; larger in Rosbergen et al. (+10.4 to +12.9%) than Janssen et al. (+9%, borderline)	2 (233)	Low
Social activity	Significant increase in both studies	2 (233)	Low
Cognitive activity	Discordant: nonsignificant (Janssen) vs significant (Rosbergen, P=0.002)	2 (233)	Very low
Safety (AEs, length of stay)	No difference in serious AEs; Rosbergen et al. found fewer overall AEs and shorter stay	2 (255)	Low
Function / QoL at 3 months	No significant difference in either study	2 (199)	Low

Summary of Main Findings

Both studies agreed EE increases physical and social activity while reducing inactivity, despite neither being randomized (4,9). Effects on cognitive activity were inconsistent, and neither study showed functional or quality-of-life benefit at three months. Both found EE safe; Rosbergen et al. additionally found fewer adverse events and shorter length of stay. Given the Serious (Janssen et al.) versus Moderate (Rosbergen et al.) ROBINS-I ratings, greater confidence should be placed in the Rosbergen et al. estimates, particularly for clinical outcomes.

Explaining Heterogeneity and Mechanistic Rationale

The larger effect in Rosbergen et al. likely reflects an actively staff-facilitated model (structured group sessions, communal meals) in the acute setting, versus the more patient-driven model in Janssen et al., where the individual-enrichment component was poorly implemented (in reach only 24% of the time) diluting the measured effect, consistent with the Serious D4 rating. This suggests implementation fidelity, not merely resource availability, is a key determinant of EE effectiveness (3,7). Notably, the unfavourable baseline imbalance in Janssen et al. (more severe strokes in the experimental group) would bias results against EE, so the observed benefit despite this imbalance arguably supports a genuine, if modest, effect on activity. Mechanistically, EE is hypothesized to act through activity-dependent neuroplasticity increased neurotrophic signalling, dendritic branching, and cortical reorganization during the plastic window of early recovery (5) by extending meaningful activity beyond scheduled therapy. However, this review identified only clinical activity and safety evidence, not direct neurophysiological data, so the mechanistic rationale remains inferential and warrants future study.

Clinical and Implementation Implications

EE is a feasible, low-cost, safe adjunct that increases daily activity engagement and, in acute settings, may reduce adverse events and length of stay. Both programmes required minimal additional resourcing (~AUD $10,000 and staff training for Janssen et al.; existing staffing with education sessions for Rosbergen et al.), supporting broad implementability. However, poor fidelity of individually tailored enrichment in Janssen et al. suggests services should prioritize communal, staff-facilitated activities with active fidelity monitoring rather than passive bedside availability. As neither study showed functional benefit at three months, EE should be framed as increasing meaningful daily engagement rather than as a proven treatment for long-term disability.

Strengths and Limitations of This Review

This review's strengths include a systematic four-database search, explicit PICO-based eligibility criteria, structured OCEBM appraisal, a formal ROBINS-I risk-of-bias assessment suited to the nonrandomized designs included, and qualitative certainty ratings per outcome. Limitations include: only two nonrandomized studies (OCEBM Level 3b) met eligibility, with no RCTs or existing systematic reviews identified, limiting power and precluding meta-analysis or publication-bias assessment; the review was not prospectively registered (e.g., PROSPERO), raising susceptibility to selective reporting; study selection, appraisal, and

ROBINS-I judgements were conducted by a single reviewer without independent duplication, a recognized source of bias; EE lacked a standardized protocol across studies, differing in components, dose, setting, and staffing, which precluded pooled or dose-response analysis; and neither study was powered for long-term functional outcomes, so the absence of benefit should be read as inconclusive rather than as evidence of no effect.

Implications for Future Research

Larger, adequately powered multicentre RCTs are needed, using a standardized, manualized EE protocol with pre-specified fidelity monitoring, prospective registration, and blinded outcome/appraisal processes. Where randomization is infeasible (e.g., ward-level interventions), stepped-wedge or interrupted-time-series designs with concurrent controls should be prioritized to address the secular confounding identified as this review's principal ROBINS-I concern. Future trials should be powered for functional and quality-of-life endpoints at three months and beyond, report enrichment dose to enable dose-response analysis, and examine implementation determinants (staffing, ward design, organizational culture) as effect modifiers (3,7).

CONCLUSION

This systematic review synthesized comparative evidence on environmental enrichment (EE) during early inpatient stroke rehabilitation and identified two nonrandomized controlled studies that met the eligibility criteria. Both studies reported increased overall, physical, and social activity and reduced inactivity following EE interventions compared with usual ward-based care. These improvements were generally greater and more consistent in acute stroke units than in subacute rehabilitation settings, where limited adherence to individually tailored enrichment protocols may have attenuated the observed effects. Neither study identified an increased risk of adverse events associated with EE, and one reported fewer adverse events and a shorter length of stay, with the latter finding maintained at six months. However, neither study demonstrated statistically significant improvements in functional outcomes or quality of life at three months, and findings regarding cognitive activity were inconsistent. The certainty of evidence ranged from low to very low across all outcome domains because of the nonrandomized study designs, overall risk-of-bias ratings of serious and moderate, and the limited evidence base. The principal methodological concerns included uncontrolled secular confounding and substantial differential attrition in one study, while the other was limited by its before-and-after design and the absence of blinding among treating personnel. Overall, the findings suggested that EE may be a feasible, potentially low-cost adjunct to early inpatient stroke rehabilitation that promotes meaningful daily engagement. However, the available evidence was insufficient to establish its safety conclusively or demonstrate sustained improvements in functional recovery and long-term disability.

Future research should prioritize larger, adequately powered, multicenter randomized controlled trials using standardized, manualized EE protocols, prespecified intervention fidelity assessments, prospective trial registration, and blinded outcome assessment. When individual randomization is impractical, cluster-randomized or stepped-wedge trial designs should be considered. Alternatively, controlled interrupted time-series designs may help address temporal confounding when randomization is not feasible. Future studies should be

adequately powered to detect clinically meaningful changes in functional outcomes and quality of life at three months and beyond, quantify intervention exposure to facilitate dose–response analyses, and examine implementation factors, including staffing levels, ward design, and organizational culture, as potential effect modifiers. Given the apparent importance of intervention fidelity, researchers should systematically assess adherence to both communal and individually tailored enrichment components. Direct neurophysiological measurements would also help clarify whether the observed behavioral improvements were associated with activity-dependent neuroplasticity, a proposed mechanism that remained insufficiently established by the included studies. Finally, the lack of standardized EE protocols limited comparability and precluded meaningful quantitative synthesis. Establishing consensus on core intervention components, dosage, and delivery procedures would strengthen methodological consistency and facilitate comparisons across future studies.

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CONFLICT OF INTEREST

The author declares that there are no conflicts of interest related to the conduct of this research or the preparation of this manuscript. The research was not influenced by any commercial, financial, institutional, or personal relationships that could potentially affect the objectivity of the research process or the interpretation of the findings.

AUTHOR CONTRIBUTION

The author was fully responsible for all stages of the research process, including conceptualization, methodology development, data collection and analysis, interpretation of findings, manuscript preparation, and revision. The author also reviewed and approved the final version of the manuscript and takes full responsibility for the content, accuracy, and integrity of the submitted work.

GENERATIVE ARTIFICIAL INTELLIGENCE USAGE STATEMENT

In preparing this manuscript, the author used artificial intelligence (AI) tools in a limited capacity for grammar improvement and language checking. AI was not used to generate data, conduct analyses, determine research findings, or develop scientific interpretations. All substantive content, data, analytical results, interpretations, and conclusions remain the sole responsibility of the author.

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