Exploration of Neuroprotective Therapy

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Effect of gardening physical activity on neuroplasticity and cognitive function

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Abstract

Background: The beneficial effects of gardening as a form of physical activity have garnered growing interest in recent years. This research aimed to evaluate the effect of gardening as a physical activity on promoting neuroplasticity and cognitive functioning in people.

Methods: A systematic review was conducted on published articles between January 2010 to December 2022. The systematic search identified 3,470 records based on the PRISMA recommendations, 23 studies were eligible for inclusion in the review.

Results: The study revealed the potential benefit of gardening physical activity on brain health. The evidence suggests that engaging in gardening physical activity not only boosts immunity and lowers inflammation but can also increase levels of growth neurotrophic factors like brain-derived neurotrophic factor (BDNF), vascular endothelial growth factor (VEGF), and platelet-derived growth factor (PDGF), which are essential for promoting neuroplasticity and improving cognitive function. These results should be interpreted cautiously given the small number of included studies and few randomized controlled trials.

Discussion: The study results of gardening physical activity are promising. However, to adequately comprehend the underlying mechanism of the physical activity of gardening on brain health, more well-designed research is still necessary.

Keywords

Neurorehabilitation, neuroplasticity, growth neurotrophic factor, cognition

Introduction

One of the most difficult global health and social issues today is the prevention of cognitive decline or the restoration of cognitive function [1, 2]. Many previously incurable disorders are now treated as chronic illnesses thanks to access to cutting-edge treatment. Because of this, there is a substantial risk for neurocognitive problems, Alzheimer's disease (AD), and AD-related dementia (ADRD). According to research, low-middle-income countries are particularly at risk and are expected to have the biggest rises in dementia connected to AD and other forms of dementia [3]. Of particular interest, there is a growing concern that cancer treatments like chemotherapy may accelerate the cognitive aging process of the brain, increasing the risk for future neurodegenerative conditions [4]. Several clinical studies have demonstrated cortical degeneration associated with changes in the brain and cognitive impairment from pre- to post-anthracycline-based chemotherapy in patients with breast cancer [5]. These changes have been attributed to chemo-neurotoxicity which has been shown to play a central role in blood-brain barrier penetrability resulting in vascular and oxidative damage, neuroinflammation, neuronal dysfunction, as well as glial cell damage, while some studies have shown that the presence of epsilon 4 allele of apolipoprotein E (*APOE*) also to be a genetic risk factor for cognitive dysfunction [6–8].

Previous studies showed the brain's default mode network which includes precuneus, cingulate, medial frontal, middle temporal, and lateral parietal regions, including the hippocampus is particularly vulnerable to anthracycline-based chemotherapy in breast cancer patients [9]. The default mode network has a significant function in implicit learning, monitoring, and distribution of neural resources to various cognitive processes. In the frontal-striatal and temporal regions of the brain, functional magnetic resonance imaging (fMRI) studies demonstrated diminished white matter and grey matter integrity after chemotherapy treatment [10]. Particularly, in cancer survivors treated with anthracyclines, brain-derived neurotrophic factor (BDNF) levels were low with frontal lobe and hippocampal neuronal loss [11]. Studies have consistently shown that these brain changes correspond with cognitive impairments, including memory and learning [12], attention, concentration, information processing speed, and executive function [13] in non-central nervous system cancer patients treated with anthracycline-based chemotherapy. The cognitive impairments can be long-lasting and tend to be one of the most common limitations to quality of life and well-being amongst survivors.

Promoting brain function or preventing the onset of cognitive impairment continues to be one of the most challenging health-related challenges, especially in resource-limited countries, including South Africa. The evidence showed that anthracycline-based chemotherapy is a commonly used regimen in South Africa and worldwide to treat cancer despite the neurotoxicity. In a recent study, we found that cognitive impairment is associated with neuroinflammation in a cohort of patients treated for breast cancer with an anthracycline chemotherapy regimen in South Africa [14]. Yet, access to effective neurorehabilitative treatment for cognitive disorders remains a major clinical challenge [15].

South Africa is a highly unequal society, with the majority of the people not having access to specialized oncology and neuropsychology care [16]. While technology-based cognitive training interventions have demonstrated their potential in neurorehabilitation [17], in a developing country like South Africa structural challenges, including to access computerized cognitive rehabilitative interventions due to technological illiteracy, undereducation, a lack of financial resources for internet data, smartphones, or laptops can potentially be a major barrier [18]. This forces us to think contextually and find local solutions that are consistent with the contextual realities of local people. No simple intervention exists to prevent, preserve, and restore cognitive impairment in diseases, but it is important that we consider interventions that are feasible for the local context, like forms of physical activity.

Background

Existing evidence links physical activity to brain health. Findings from studies showed a relationship between physical activity and cognitive improvement in other neurodegenerative diseases associated with cognitive decline, such as Alzheimer's and Parkinson's disease [19, 20]. The evidence suggests that physical activity is responsible for the promotion of neuroplasticity, in that it can lead to the upregulation of BDNF, downregulation of endogenous corticosteroids and pro-inflammatory cytokines, reduction of oxidative stress, and improved cerebral blood flow and preservation of brain volume [19–22]; all of which contribute to improved brain health and preservation of cognitive function in neurodegenerative diseases and patients with neurological injuries [23].

Recent studies have also demonstrated the potential health benefits of gardening as a physical activity likened to aerobic [21, 24] and muscular exercise [25]. Indeed, gardening is arguably one of the most common ways of interacting and is a popular form of leisure activity in many communities in many countries, including South Africa. Previous studies showed that gardening promotes psychological health, and social connection, and improves life satisfaction. A meta-analysis of 22 studies showed that gardening activity was associated with a reduction in depression, anxiety, stress, and fatigue [26]. The physical activity of gardening does present a feasible neurorehabilitation intervention with the potential to promote neuroplasticity and improve overall brain health.

The research on the advantages to brain health seen in those who participated in gardening physical activity is underpinned by several theories. According to the attention restorative theory, being in a natural setting with natural plants can help to relieve stress and restore direct attentional ability after mental and cognitive exhaustion [27]. The stress recovery theory contends that therapeutic gardening activities promote feelings of control, cooperation, and support while reducing stress [28]. Existing evidence-based neuroscience research offered empirical support for these hypotheses, indicating that gardening as a physical activity benefits cognitive skills, including attention and memory, and activates core brain networks that produce positive emotions (such as feeling in control, happiness, and stress reduction) [29].

As a low-to-moderate intensity physical activity, gardening can be done on an individual's own time, does not require much supervision from professionals, is accessible, and is an activity that poses a low risk of injury. It can potentially trigger neurogenesis and promote neuroplasticity which can lead to cognitive benefits for people with chemotherapy-induced cognitive impairment and other related conditions with cognitive decline and dementia risk. Scientific evidence of the therapeutic mechanism of short-term gardening activity for memory improvement has already been shown [26]. In consequence, gardening is a low-cost effective, and contextually relevant health intervention that can support cognitive maintenance and restore cognitive function without adding any further load to everyday function. It has the potential to improve the quality of life for persons with neuropathological changes secondary to disease (i.e., malignancies, diabetes, hypertension) and neurotoxic treatment (i.e., chemotherapy) in developing countries and can be easily incorporated into clinical settings as part of neuroprotective and neurorestorative rehabilitative intervention. This paper presents a synthesis of evidence on the effects of gardening as a physical activity on promoting neuroplasticity and cognitive function. This study proposes the question: What are the effects of gardening physical activity on brain health?

Materials and methods

Design

The current study was performed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) recommendations [30]. Figure 1 shows the different phases defined in the study methodology. Published quantitative and qualitative studies were reviewed.

Terminology

In this study, the term "gardening" refers to any activity in which individuals grow, nurture, and/or care for plants (flowers and/or vegetables) for non-commercial purposes. This term includes but is not limited to active activities, such as seeding, digging, propagating, planting, watering, ranking, mowing, weeding, harvesting, and activities that require engagement with soil and plants, carried out in private gardens but also allotment and public gardens. Gardening and horticulture are terms that are used interchangeably in this review study to refer to the physical activity of performing gardening tasks.

Search strategy

Articles included in this review were published between January 2010 to December 2022 and were searched using several databases, namely, PubMed and Scopus, and other websites, with a focus on three primary topic areas: "gardening", "cognitive function", "neuroplasticity" (Table S1). The following Medical

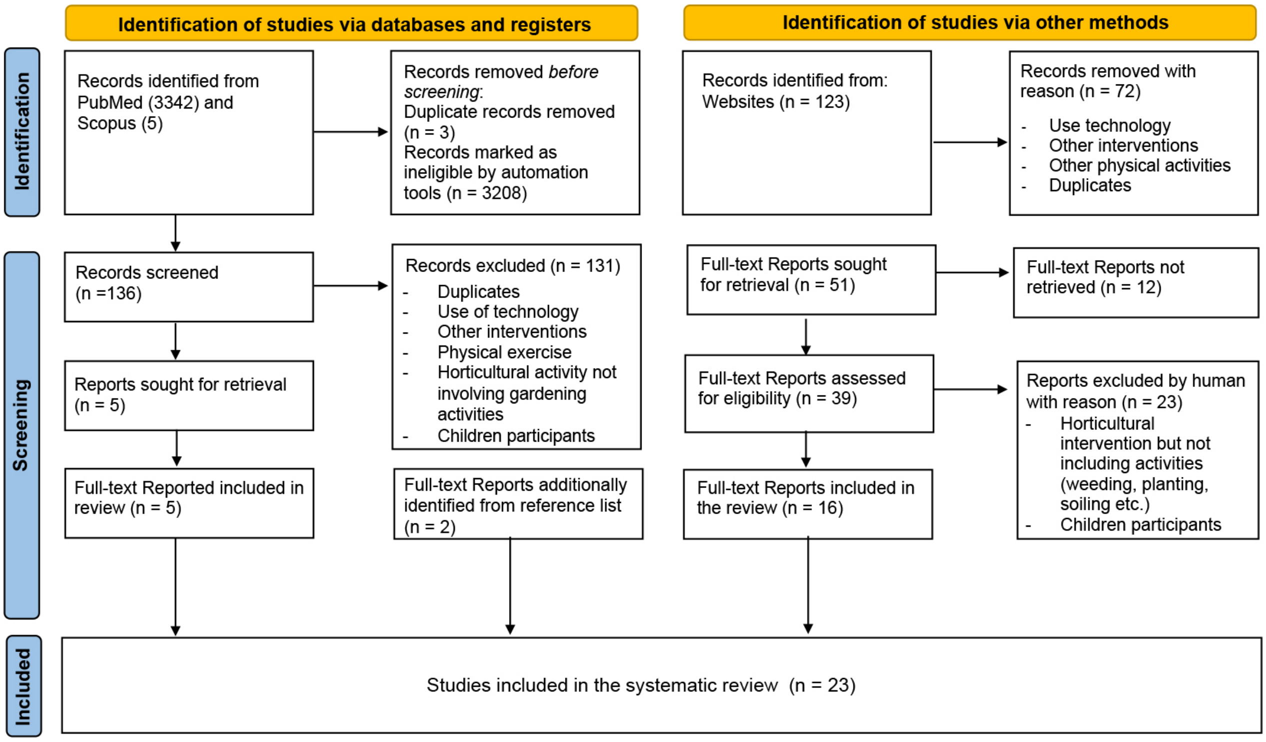

Figure 1. Study selection according to the Preferred Reporting Item for Systematic Reviews and Meta-Analyses (PRISMA) statement

Subject Heading (MESH) search terms were used in their singular or plural forms in the titles, abstract, keywords, and text fields of the articles: "Gardening" OR "Horticultural therapy" AND "Cognitive Functioning" OR "Cognition" AND "Brain-derived neurotrophic factor". Additional web searching was conducted to identify studies not retrieved and indexed in the searched bibliographic databases, and a reference list of all included articles was also manually screened to identify additional studies following a snowball procedure. The quality of each included article was evaluated for quality and risk of bias (Table S2 and S3).

Screening and eligibility

Independent reviewers searched (BM, TN, SM), assessed eligibility, and extracted data (AGL, TM). The articles were selected according to the following procedure while considering the review's defined inclusion and exclusion criteria: 1) written in English, 2) between the years 2010 and 2022, 3) utilizing gardening as a form of physical activity intervention, and 4) promote neuroplasticity (as measured by any one or more brain growth factors, i.e., neuroproteins and/or myokines) and cognitive improvement, performed with human studies. Articles included the following PICOS criteria [31].

Population

Eighteen years and older with cognitive impairment where gardening as physical activity was used as an intervention. For nonclinical populations, we included, healthy groups, young people but age of consent (18+), older people (including geriatric).

Interventions/exposure

Studies that used gardening physical activity programs as an intervention or exposure were included. Patients with neurodegenerative disease [i.e., Alzheimer's, Parkinson's, traumatic brain injury (TBI), chemo-brain] or other neurodegenerative processes, and/or healthy population, that used gardening as cognitive intervention were included.

Comparisons

No comparison group were required but where it was included based on research design, we included those studies as well.

Outcomes

Cognitive function included one or more of the cognitive domains and associative brain structures. Expression of any one or more growth neurotrophic factors/neuroproteins and/or myokines through gardening as a physical activity. Psychophysiological indicators, and psychological distress, including anxiety and/or depression, and fatigue.

Study type/design

Quantitative studies, including randomized controlled trials (RCTs), quasi-experimental intervention studies, and qualitative studies were included.

Data extract

The data studies were extracted from pre-established databases followed by an independent assessment of the titles and abstracts retrieved from the literature searches for relevance. The basic information extracted from these studies included: 1) information about the article; 2) information about the participants; 3) information about the study's features; 4) information about the data collecting; and 5) the study's main conclusions. All extracted data was transferred into a spreadsheet in Excel. The reviewers independently verified the extracted data. Discrepancies were resolved by consensus discussion to minimize the potential for information bias and misclassification errors.

For the quality and risk of bias assessment for each article included in the research, the QualSyst tool was used [32]. For the quantitative studies, 14 items were scored depending on the degree to which the specific criteria were met ("yes" = 2, "partial" = 1, "no" = 0). Items not applicable to the study design were marked "N/A" and were excluded from the calculation of the summary score.

For each paper, the total score was added up across all pertinent items [(number of "yes" × 2) + (number of "partial" × 1)] and divided by the total potential score [i.e., 28 – (number of "N/A" × 2)] to arrive at a summary score. Scores for the qualitative studies were calculated similarly, based on the scoring of ten items, excluding "N/A". The QualSyst score of 80% or higher (strong quality), 60–79% (good quality), 50–59% (adequate quality), and 50% or lower (poor quality) (Table S2 and S3).

Data synthesis

A systematic narrative synthesis of findings from studies was conducted [33, 34]. In this narrative synthesis process combining different types of evidence and exploring relationships within and between studies were considered and are presented as themes. This study used a textual technique to summarise and explain the conclusions of the synthesis of the included papers in the systematic review, adhering to the narrative synthesis method [35].

Synthesis of risk of bias

The review is susceptible to several risks of bias that are unavoidable. The interpretations and findings emanating from this review must be carefully considered in light of the inherent bias. As a means of minimizing risks of bias, the review followed and adhered to the PRISMA criteria and guidelines. However, publication bias is unavoidable, and given the exclusion determined priori criteria, only studies that were available in the public domain and published in English. Each of the included studies was subjected to methodological appraisal for inclusion. Several studies had very small samples with a lack of randomization (n = 17) and control comparative groups, which also invoked bias in the interpretation.

Results

Descriptive summary

The systematic search generated 3,347 English-language potential publications from two databases, PubMed, and Scopus. From the total number of articles, after removing duplicates, and screening the abstracts and titles, 136 papers were identified as relevant for full-text evaluation. Of these, 131 were eliminated during the full-text screening because they were not focused on gardening activities, they used technology or games, or the study sample did not include adults (18 years or older). The final selection of eligible articles that were included was 5.

An additional 123 articles were identified via another third method (website search) of which 39 full text was screened for inclusion. After screening and review following PRISMA 2020 guidelines, a total of 23 articles were eligible for inclusion in the review (Figure 1).

Studies in this review were published from 2013 to 2022 and were largely clustered in Asia (16), North America (4), and Europe (3), with the research primarily driven by South Korea (Table 1). It is also important to note that within the last two years, there have been several studies related to the topic, demonstrating the potential of this field in neuroscience. The majority of studies were quantitative studies (19), qualitative (3), and mixed-method (1). Of these studies reviewed, a total of 6 were randomized control and 1 non-randomized controlled study, while the rest (16) were quasi-experimental studies. All studies were of sufficient quality to be included in the review (Table 1).

Brain health benefits of gardening physical activity

The synthesis is based on studies from a wide range of disciplines, including psychology, neuroscience, agricultural science, physiology, and experimental biology. The synthesis revealed several health benefits associated with gardening as a physical activity.

Gardening physical activity on levels of brain growth factors/neurotrophins

The evidence supports that gardening physical activity is responsible for the expression of brain growth factors, including BDNF, vascular endothelial growth factor (VEGF), and platelet-derived growth factor (PDGF) in human participants [36, 37]. In two separate studies, increased plasma BDNF levels were observed after gardening physical activity. For example, Park et al. [36] found that levels of BDNF were significantly increased in participants after 20 minutes of gardening which was equivalent to low-to-moderate-intensity physical activity. Despite the limitation of the study design (pre-post-test design), this is an important finding showing increased BDNF levels associated with gardening. The research elsewhere showed that BDNF serves as an important regulatory mechanism for the activation of neuronal cell proliferation and growth, which promotes cognitive recovery, improved memory function, and may decrease the risk of dementia [21]. An increase in BDNF after engaging in gardening physical activity intervention holds promise since BDNF has direct benefits for brain health, especially the improvement in memory and neuronal proliferation. However, the direct causal nature of this relationship needs to be ascertained in a randomized control design. Similarly, in another study, the researchers investigated the effects of gardening activity on cognitive health in the elderly. The study showed that a 24-session gardening program (twice weekly four-hour) was associated with significantly increased BDNF levels that were found to be related to improved cognitive health of the elderly participants when compared to participants in the non-gardening control group [37]. The study used a pre-post comparative design. Significantly this study found that the gardening group not only showed increased cognitive ability, as evaluated on the Korean Mini-Mental Status Examination (MMSE) test, but also significant improvement in hand dexterity after the gardening program. The generalisability of this study was curtailed by the small sample size and non-randomization of the groups. It is important to note that the study did not follow up with the participants to determine if the benefits were maintained over time. One Japanese single-blind RCT study of a horticultural intervention involving 20 weekly 60–90 minutes sessions involving planting, cultivating, growing, and harvesting crops was compared with exercise intervention (20 weekly 90-minute

Table 1. Main characteristics of the included articles

Author Year	Results	Intervention Protocol	Outcome measured	Age and gender	Participant count	Location	Study design	Quality assurance**
Park et al. (2020) [37]	Tryptophan, kynurenine, and serotonin may be useful as metabolic biomarkers for improved cognitive ability by the gardening intervention.	Engaged 24 sessions of 60 min gardening activity sessions twice per week of activities involving garden design and planning, planting transplants, sowing seeds, cutting, garden maintenance, and hydroponics.	• Cognitive ability • Brain-derived neurotrophic factor (BDNF) • Serum metabolites • Korean Mini-Mental State Examination (MMSE)	71.8 ± 4.8 50% ♀	40	Korea	Quasi-experimental	79%
Yang et al. (2022) [54]	Therapeutic gardening is promising and applicable as a nature-based intervention to improve the mental health of individuals experiencing psychological distress especially in the COVID-19 pandemic.	A therapeutic gardening program that involved engaging in setting up kitchen garden, setting up seasonal bed, setting up herb bed, health lecture, setting up aquatic garden, setting up rock garden, sowing, mulching, composting and irrigation, removing weed as a group for 30 sessions for 3 h twice per week for 15 weeks.	• Depression: Mental Health Screening Tool for Depression (MHS:D) • Anxiety: Mental Health Screening Tool for Anxiety (MHS:A) • Daily activities: The Engagement in Daily Activity Scale (EDAS) • Quality of life: World Health Organization Quality of Life—Brief (WHOQOL-BREF) • Mindfulness: Korean Mindful Attention Awareness Scale (MAAS)	55.5 79% ♀	111	Korea	Multi sites trial	95%
Park et al. (2019) [36]	The levels of brain nerve growth factors related to memory were significantly increased after the gardening activity in senior adults.	A 20-min gardening activity intervention with low-to-moderate intensity gardening activities such as digging, raking, planting/transplanting, fertilizing, and watering.	• BDNF levels • Vascular endothelial growth factor (VEGF) levels • Platelet-derived growth factor (PDGF) levels	76.6 ± 6.0 68% ♀	41	South Korea	Pre-post intervention study	100%
Kotozaki (2020) [50]	Provide evidence that the effects of gardening activities on the psychological health of postpartum women.	Engagement in 8 weeks of gardening activity involving planting and nurturing plants, weeding, and gathering flowers they grew, and made an herbarium of dried flowers.	• Rhythmicity score of the Revised Infant Temperament Questionnaire (RITQ) • Attachment score Mother attachment-to-Infant Bonding Scale (MIBS-J) • Stress regarding parents score-Parenting Stress Index (PSI) • Postpartum depression-Edinburgh Postpartum Depression Scale (EPDS)	30.4 ± 3.2 100% ♀	15	Japan	Exploratory pre- and post-intervention pilot study	95%
Kotozaki (2020) [55]	Horticultural activity may improve mental health and cognitive functions in postpartum women.	Engagement in 8 weeks of gardening activity involving planting and nurturing plants, weeding, and gathering flowers they grew, and made an herbarium of dried flowers.	• The trail making test (TMT)-A and TMT-B were significantly decreased. • The Digit Symbol Substitution Test was significantly increased. • The Edinburgh Postpartum Depression Scale, State-Trait Anxiety Inventory,	30.4 100% ♀	15	Japan	Exploratory pilot study	95%

Table 1. Main characteristics of the included articles (*continued*)

Author Year	Results	Intervention Protocol	Outcome measured	Age and gender	Participant count	Location	Study design	Quality assurance**
			and anger hostility, confusion-bewilderment, fatigue-inertia, tension-anxiety, Total Mood Disturbance of the Profile of Mood States 2 was significantly decreased, respectively. • Vigor-activity and friendliness of the Profile of Mood States 2 were significantly increased.					
Han et al. (2018) [40]	Horticultural therapy can improve the stress levels and physical functional abilities of elderly people with mental health problems.	A horticultural therapy program that involved 10 once a week 90 min sessions of plant cultivating activities such as making plant beds, planting transplants, watering, weeding, and harvesting.	• Cortisol levels • Physical functional ability	80.1 92% ♀	28	South Korea	Pre- and post-test design with experimental and control groups	79%
Van Den Berg & Custers (2011) [39]	Gardening can promote relief from acute stress. Reported on reduction of cortisol levels and mood regulation.	30 minutes of outdoor gardening or indoor reading	• Salivary cortisol levels • Self-reported mood	57.6 73% ♀	30	The Netherlands	Experimental design	79%
Smith-Carrier et al. (2021) [52]	Therapeutic gardening is a valuable practice for people with dementia.	Therapeutic gardening that involved series of six waves that involved planning, planting, tending, pruning and harvesting for five months in groups.	• Engagement • Quality of life • Well-being • Positive mental and physical well-being	Elderly	6	Canada	Qualitative design	95%
Widodo et al. (2019) [47]	Horticultural therapy to plant flowers had a positive effect on stress levels in the elderly.	Horticultural therapy was an activity of planting and caring for flower plants through planting, weeding, watering, fertilizing for 6 months.	• Qualitative picture of brain waves or brain mapping about stress	45–59 21% ♀	14	Indonesia	Quasi experimental design	71%
Christie et al. (2016) [49]	Immersion in horticultural activity may be an effective treatment modality in promoting positive health benefits to service users.	A 12-month horticultural therapy intervention that involved raking, digging, planting, watering, adding mulch and potting up plants.	• Subjective health • Wellbeing • Reduced stress • Life satisfaction	52.3 71% ♀	7	UK	Qualitative design	90%
Hassan et al. (2018) [58]	Gardening activities contribute to significant lower anxiety levels after gardening tasks.	Transplanting activity using soil with plants or translating without plants 15 min in duration	• Psychophysiological • Relaxing effects • Reduction of stress	79.5 100% ♀	40	China	Experiment design	95%
Styck and George	Gardening has a positive impact on psychological	Gardening sessions that involved watering, weeding, fertilizing, and	• Physical benefits	> 50 90% ♀	10	Michigan	Cluster randomized	95%

Table 1. Main characteristics of the included articles (*continued*)

Author Year	Results	Intervention Protocol	Outcome measured	Age and gender	Participant count	Location	Study design	Quality assurance**
(2022) [56]	wellbeing of person living with dementia.	harvesting the crops twice weekly at outdoor raised beds over a 2-month duration	• Mood improvement • Sense of community • Reminiscence • Sense of self • Sense of purpose • Pride				pilot study (Qualitative)	
Odeh et al. (2022) [60]	Group-based gardening or art-making can provide quantitatively measurable improvements in healthy women's psychosocial health status.	Group based indoor art making and 15 gardening activities that include planting seeds and vegetative propagation by cuttings/divisions; transplanting; and simulated harvest.	• Anxiety • Depression symptoms • Mood disturbance • Stress • Satisfaction with discretionary social activities • Quality of life measures • Cardiac physiological data (heart rate and blood pressure)	32–33 100% ♀	42	Gainesville or Florida	Randomized controlled trial	96%
Makizako et al. (2019) [38]	Exercise may improve memory, while horticultural activity may not.	Exercise and horticultural activities involving 20 weekly 60- to 90-min sessions involving group crop-related activities such as cultivating, growing, and harvesting.	• Geriatric Depression Scale-15 (Gds-15) • Wechsler Memory Scale-Revised • Walking speed • 2-minute walking test scores • Social network • Life space • Subjective daily physical activity	73.1 50% ♀	89	Japan	Randomized controlled trial	93%
Vujcic et al. (2017) [57]	Nature-based therapy is recommended to psychiatric patients as a form of occupational or supportive therapy.	Horticulture therapy that involved exposure to green environments and plot weeding and potting collected fruits thrice a week for an hour for four weeks.	• Depression • Anxiety • Stress	45.35 70% ♀	30	Serbia	Randomized controlled trial	75%
Kim et al. (2021) [43]	Activities of transplanting have a positive effect on the cognitive function of elderly people by increasing brain activity.	Horticultural and nonhorticultural activities as leisure activities	• Relative beta index • Gamma index • Low beta index • Ratio of sensorimotor rhythm to theta indices • Total mood disorder score	74.0 50% ♀	58	South Korea	Cross-over experimental design	95%

Table 1. Main characteristics of the included articles (*continued*)

Author Year	Results	Intervention Protocol	Outcome measured	Age and gender	Participant count	Location	Study design	Quality assurance**
Hewitt et al. (2013) [53]	A meaningful guided activity program can maintain or improve well-being in the presence of cognitive deterioration.	2 hours per week structured activity programme of gardening	• MMSE • Bradford Well-Being Profile • Large Allen Cognitive Level Screen (LACLS) • Pool Activity Level (PAL)	43–65 67% ♀	12	UK	Mixed-method study	95% (quantitative) 100% (qualitative)
Lai et al. (2022) [29]	Evidence that gardening can stimulate functional connectivity in the brain, activation of positive emotions, and mindfulness in the brain.	Three stages of horticultural activities of site preparation and sowing, fertilizing and weeding, and harvesting for 6 weeks	• Physiological changes during different stages of horticultural activity • Functional magnetic resonance imaging (fMRI) functional connectivity of brain regions • Activation of positive emotions • Mindfulness in the brain • Creativity • Attention • Relaxation • Reduction of depression	23 47% ♀	23	Taiwan	Pre-post experimental study	95%
Lee et al. (2021) [44]	Results showed that each horticultural activity showed promotion of brain activity. Study confirmed the possibility of horticultural activity as a short-term physical intervention to improve attention levels and emotional states.	Engagement in horticultural activities that involved raking, sowing seed, hoeing, weeding, pruning, watering, over two minutes intervals and one-minute rests for 90 minutes.	• Brain activity • Emotional changes • Attention level • Fatigue • Tension • Vigor	24.97 ± 2.62 50% ♀	60	Korea	Experimental study	95%
Masuya & Ota (2014) [51]	Elderly people with mild to moderate dementia improved after participation in the horticultural activities program.	Horticultural activities such as seeding and transplanting plants into individual pots, thinning and harvesting them for 30–40 min once a week for six consecutive weeks.	• Vitality index (Vi) • Geriatric Depression Scale (Gds-15) • Activities of Daily Living (ADL-20) Scale • Quality of life • MMSE	88 82% ♀	9	Tokyo	Non-controlled trial	100%
Tao et al. (2022) [59]	Choosing suitable plant types in horticultural activities is positively significant in enhancing affect.	Horticultural activities that involved digging, transplanting, and watering for 30 min	• Blood pressure • Positive/negative affects • Heart rate variability (RMSSD, SDNN, And LF/HF)	22.5 Gender not reported	152	China	Randomized field-controlled trial	86%

Table 1. Main characteristics of the included articles (*continued*)

Author Year	Results	Intervention Protocol	Outcome measured	Age and gender	Participant count	Location	Study design	Quality assurance**
			• Controlled covariate environmental parameters (field temperature, humidity, and noise)					
Toyoda et al. (2017) [46]	The need for collating external information corresponding to changes in the external environment induced repeated frontal pole activation during the gardening tasks.	Engagement in repeated gardening tasks involving seeding task and a watering task	• Activation of the frontal pole • Oxygenated hemoglobin values in the frontal pole	67.7 63% ♀	24	Japan	Quantitative design	100%
Ng et al. (2018) [42]	Horticultural therapy can reduce plasma interleukin-6 (IL-6), thus may prevent inflammatory disorders, and through maintaining plasma CXCL12 (SDF-1α), may maintain hematopoietic support to the brain. Thus, may enhance the well-being of older adults.	Engagement in 15 sessions of horticultural activities involving indoor gardening, growing, maintaining and harvesting vegetables and herbs, as well as guided walks in the various parks	• IL-1β, IL-6, sgp-130 • CXCL12/SDF-1α, CCL-5/RANTES • BDNF • Cortisol and DHEA (dehydroepiandrosterone) • Cognitive functions • Depression • Anxiety • Psychological well-being • Social connectedness and satisfaction with life	67.1 Gender not reported	59	Singapore	Randomized controlled trial	79%

< 50%: poor quality; 50–59%: adequate quality; 60–79%: good quality; > 80%: strong quality; ♀: female; **: QualSyst tool for quantitative and qualitative studies was used to appraise the quality. The mixed method was appraised by evaluating both checklists [32]

aerobic muscle strength training, postural balance training, and dual-task training) and educational control group (90-minute didactic education on topics on traffic safety and disaster prevention). While BDNF levels were evaluated in their study, the researchers did not explicitly discuss the outcome of the different interventions on BDNF levels [38]. Additionally, none of the studies had adequate control of factors such as motivation, sense of achievement, self-expression, and measures of meaningful activity engagement.

Gardening physical activity on metabolic biomarkers regulation

In some human studies, gardening applied as a physical activity was beneficial in promoting tryptophan biosynthesis, kynurenine, and serotonin metabolism [37]. The evidence suggests that tryptophan metabolism is related to cortisol levels. In another study, cortisol levels were regulated during gardening activity in elderly participants [39]. In this study, participants were exposed to a stressful task that involved a modified Stroop task with a social pressure component to induce mental stress. The computer task with 10 tests and 200 experimental trials required participants to identify the color of a word “red” or “blue” by pressing two selected keys. After 100 trials, false feedback was given. After 200 trials, a score out of 10 was given, but the maximum score was manipulated to be 7. To add a social pressure component, the participants had to show their low scores to the researcher. Participants were then randomly assigned to a gardening-only intervention on their own or a reading-only intervention. Cortisol levels decreased significantly during gardening compared to reading, especially during the latter half of the activity. Additionally, in the post-activity phase, after 30 minutes, the group that had spent time gardening outdoors had marginally lower cortisol levels than the group that had spent the same amount of time reading indoors. When compared to the reading-only group, the participants in the gardening group significantly recovered from acute stress after 30 minutes of outside gardening with a positive effect on mood [39]. Cortisol plays a vital role in regulating the metabolism of how the body uses fat, proteins, and carbohydrates for energy. In addition, it is also an effective anti-inflammatory hormone that suppresses inflammation. According to research by Han and colleagues [40], individuals who took part in a gardening program saw a significant drop in cortisol levels between before and after the horticulture intervention. This reduction in cortisol was linked to enhanced physical functioning, better focus and attention, and less stress. Similarly, kynurenine metabolites correlate with plasma levels of interleukin-6 (IL-6), INF-gamma, and IL-2 [41], which was found to be significantly reduced after gardening physical activity as a rehabilitation program for patients. Also, after engaging in gardening activities, high levels of serotonin were linked to decreased levels of IL-6 and elevated levels of BDNF [37]. This is in line with the findings from another randomized control trial on immune and endocrine biomarkers, in which gardening physical activity was found to significantly lower plasma IL-6 levels, prevent inflammation, and provide hematopoietic support to the brain, all of which was associated with neuroprotection in the engaging group [42]. In addition, the group that engaged in gardening activities (15 sessions with ranging activities growing, maintaining, and harvesting crops, 1 hour weekly for three months and thereafter monthly for three additional months), maintained chemokine CXCL12 (SDF-1α) levels, suggesting that compared to the control group (no-gardening physical activity) they were able to preserve their cognitive function and maintain hematopoietic brain support. Furthermore, no significant change in CXCl5 (RANTES) was observed, suggesting that the physical activity of gardening played a protective role in inflammation (as seen in the reduction in IL-6 levels) and its potential role in neuroprotection. Together these studies provide evidence that suggests that participating in gardening physical activity may have beneficial effects in delaying or even preventing inflammation which is associated with a higher risk of dementia, depression, and cardiovascular disorders.

Gardening physical activity activates brain activity

Some recent advances in non-invasive neurophysiological and neuroimaging techniques have also added value to the neurological, physiological, and cognitive benefits of gardening physical activity [29, 43–47]. The evidence suggests that gardening physical activity can stimulate functional connectivity in the brain that is associated with cognitive and emotional benefits.

Neurophysiology

Studies reported brain activity of the prefrontal cortex (PFC) measured by electroencephalography (EEG) during several types of gardening activities [44]. The research showed that 1-min rest and the 2-min task of gardening physical activity were associated with higher brain activity on wearable EEG parameters (i.e., RB, SMR, theta, SEF50, and ASEF50). As a low-to-moderate-intensity physical activity, gardening was found to increase oxygenated cerebral blood flow in the PFC, as reflected in brain activation on the EEG. Significantly, the researchers found that the neurophysiological effects were particularly associated with higher brain activity on specific gardening tasks such as digging, ranking, branch cutting, and pruning. This finding is important since a great deal of planning and decision-making must go into cutting a branch, while fine-motor skills and attention resources have to be used as reflected by increased brain activity. Increased activation in the PFC leads to increased attention and concentration, which improves higher-order executive cognitive functions such as planning and organization ability [48]. The neurophysiological mechanism thus represents the brain’s capacity for adjusting to novel situations, which positively affects learning and memory processes [44]. Similar support was reported in a cross-over experimental study conducted by Kim and colleagues [43], which involved 58 adults engaging in four gardening activities for 2-minute intervals. The results showed that the cortical electric activity was highly active in the PFC of the participants during the activities of transplantation of seeds, sowing seeds, digging in soil, planning, and organizing the layout of the plants. Particularly, during the seeding activity, there was a significant increase in brain activity in the left PFC. This study concluded that the participant's concentration and attention during this task significantly increased as reflected by the cortical activity.

Neuroimaging

Similarly, the latest neuroimaging technology has given researchers the chance to further investigate the neurophysiological elements of the advantages of gardening from brain area activity through pre-post intervention fMRI studies [29]. Particularly, after 5-weeks of gardening activities, they showed that based on fMRI they were able to detect brain activity changes at different stages of the gardening activity. Lai and colleagues [29] concluded that different gardening activities activated different functional connections between the brain areas, such as activities involving preparation of garden plots, and seed sowing activated the left anterior cingulate cortex and right insula; areas known to be involved in emotional regulation, cognitive control, and motivation. In other words, these are cognitive skills necessary for decision-making, learning, cost-benefit calculation, and error monitoring. Likewise, the neurophysiological effect of garden physical activities using near-infrared spectroscopy (NIRS), a functional 16-channel (Spectratech OEG-16) headset that is attached to the participant's forehead as a noninvasive test that examines brain activation while participants performed gardening activities in a sitting posture in a quasi-laboratory setting has been reported [46]. According to the research findings, gardening was associated with repeated neural activation in the frontal lobes of participants. The evidence showed that repeated gardening task during functional NIRS (fNIRS) reading was associated with increased oxygenated hemoglobin values in frontal lobe structures, corresponding with increased concentration and attention. This study suggests that certain gardening activities effectively stimulate specific parts of the brain and could be useful in preventing dementia. Another study included MRI, to evaluate whole-brain and hippocampal volume but did not discuss the findings of this measure about the intervention (i.e., exercise vs. gardening activity) [38].

Gardening physical activity improves cognitive function

Gardening physical activity has provided benefits to promote cognitive health. Recent evidence has started to support that gardening physical activity tends to have positive effects on the central nervous system, demonstrated through improved cognitive function. The emerging body of evidence showed that gardening activity has the potential to promote memory and improve cognitive skills of attention, and concentration. Another study [49] found a 12-month gardening physical activity intervention was able to restore attention in participants. Several studies to date showed that low-to-moderate intensity gardening activity, such as making vegetable gardens or digging, weeding, and planting is associated with memory gains in elderly individuals. For example, Park et al. [37] showed that a 24-session gardening physical activity program was significantly associated with improved cognitive ability among elderly (71.8 ± 4.8 years) participants. In the study, participants who took part in the gardening intervention showed a higher cognitive score (measured by the Korean MMSE) after the intervention, compared to their pre-intervention performance. Another study [44] demonstrated the advantages of younger (24.97 ± 2.62 years) participants' attention and concentration levels by having them engage in 11 gardening-related physical activity tasks for two minutes each. Tasks including digging, ranking, and pruning resulted in a greater amount of oxygenated blood flow in the PFC as measured on the EEG, resulting in better attention and concentration. Similarly, cognitive improvement was observed in postpartum women [50]. Attentional improvement and a significant increase in processing speed were some of the observed benefits of an 8-week, once weekly gardening activity program for postpartum women. The cognitive performance of postpartum women as measured on the trail making test (TMT-A, TMT-B), and the Wechsler Adult Intelligence Scale, Third Edition (WAIS-III) digit symbol substitution test showed a significant improvement after participating in the eight-session once weekly gardening intervention. The research concluded that the added benefit of the cognitive improvement was that it translated into postpartum mothers taking better care of infants, planning daily functioning, and decision-making. The benefits of gardening activity have also been shown among patients with mild dementia. For example, Masuya and Ota [51] found that a 6-week, once weekly gardening activity intervention (12 sessions in total) was associated with improvement in vitality. The performance on the MMSE from baseline to after the 6-week intervention was comparable, with no decline in cognition. In some people with dementia, gardening activities were associated with improved activation of tactile and olfactory perception skills [52]. Participants were able to recall remoted memories which reflect activation of temporal lobe brain processing. The limitation of this study was the phenomenological self-reported design. However, Makizako and colleagues' RCT study [38] of community-dwelling individuals with mild memory issues indicated some slight improvement in logic memory delayed recall as assessed on the Wechsler Memory Scale-Revised, but the improvement was not regarded as statistically significant. This still has clinical significance because gardening can improve cognition, but it may be vital to know the dosage, or the amount, frequency, length, and type of gardening activities to partake in and whether the benefits are observed long-term or restricted to the testing conditions.

Gardening physical activity on psychological well-being and quality of life

Previous studies have considered the overall health benefits of gardening as a physical activity [53]. Overall, the research consistently demonstrated the advantages of physical activity in gardening for psychological health [54].

Self-reported assessments

According to a few studies, engaging in physical activities like gardening significantly reduces stress and improves mood. Evidence from South Korea demonstrated that gardening physical activity was useful in treating COVID-19-related psychological distress [54]. It was associated with improvement in the mental health of individuals who experienced distress during the COVID-19 pandemic. The study found that there was a significant decrease in depression and anxiety levels after the gardening intervention (3 hours twice per week for 15 weeks), as measured by the Mental Health Screening Tool for Depression (MHS:D) and the Mental Health Screening Tool for Anxiety (MHS:A), respectively. Additionally, the participants reported significant improvement in their daily activities and overall quality of life, as assessed by the World Health Organization Quality of Life–Brief (WHOQOL-BREF) scale, after the gardening intervention. In another study [49], researchers demonstrated the benefit of a 12-month gardening intervention on stress regulation among mental health service users. Similar support was found among individuals with known mental health, heart conditions, and postpartum women, older people with dementia [40, 53, 55, 56]. Kotozaki [50] conducted a study to investigate the psychological impact of engaging in eight gardening activities once a week on mothers and their infants, one year after childbirth. The study revealed that mothers who participated in the intervention showed significant improvement in their ability to predict their child's behavior, as well as an increase in their attachment to their infants. These findings were measured using the Mother's Attachment to Infant Bonding Scale. Additionally, the study revealed a significant reduction in the stressful and depressive state of postpartum mothers as measured by the Parenting Stress Index and Edinburgh Postpartum Depression Scale. The therapeutic benefit for psychiatric patients was also demonstrated. Vujcic and colleagues [57] conducted a study that revealed that engaging in activities such as weeding and potting for one hour, over four weeks, resulted in reduced levels of stress, anxiety, and depression in psychiatric patients. This was measured using the Depression and Anxiety Stress Scale (DASS21), and compared to a control group who participated in occupation activities and art therapy.

Neurophysiological and neuroimaging parameters

In addition to self-reported emotional well-being measures, a few studies showed the beneficial impact of gardening physical activity on psychological health using neurophysiological measurements such as EEG, neuroimaging, and cardiac physiological data (heart rate and blood pressure) [42, 44, 47, 58, 59]. Lee et al.

[44] found that participants showed improvement in emotional stability after participating in 11 outdoor gardening physical activities at 2-minute intervals. Brain activity in the prefrontal context corresponds with less tension. With the use of cardiac physiological measures, Odeh et al. [60] showed that the physical activity of gardening was associated with quantitatively measurable improvement in psychosocial health, i.e., reduction in anxiety, stress, depression, and quality of life. Using fMRI to detect physiological changes during the different stages of a 5-week gardening physical activity, namely, preparation and sowing, fertilizing and weeding, and harvesting; Lai and colleagues [29] showed that gardening was associated with greater activation of interneural connectivity, increased physiological relaxation, and reduced depression. Stress and depression reflect the activity of the brain. When it comes to controlling stress and improving mood, gardening is promising as an intervention that can be as effective as antidepressants [47]. In another study, the results showed that the group participating in gardening physical activity had a significantly positive impact on emotion as compared to green exercise [59]. Additionally, compared to the green exercise group, the group who did gardening physical activity demonstrated a decrease in stress and anxiety as seen by observable physiological changes. The study concluded that gardening could lift your mood just as well as other forms of physical exercise. Similar findings were observed after engaging in activities of planting, weeding, and harvesting for 10 sessions (weekly for 90 minutes) [40]. Cortisol levels were reduced significantly and correlated with improved mood, reduced stress, and improved physical functionality amongst elderly people with known mental health problems. Support was also demonstrated in a RCT showing a significant decrease in plasma IL-6 levels corresponding with decreased stress and improvement in social connectedness [42]. It would be worthwhile in future investigations to ascertain whether the effects of gardening relieving stress and improving mood are sustainable.

Discussion

This present review aimed to examine the evidence for gardening physical activity as an effective intervention that has the potential to promote neuroplasticity and improve cognitive function. To this end, the central question was whether the physical activity associated with gardening had an effect on brain health.

It is important to note that only a few studies have been conducted on the benefits of gardening, and with a very small number of these studies being randomized controlled designs. Within the limited body of evidence, this narrative synthesis of the studies included in the review revealed some emerging evidence supporting the positive effects of gardening physical activities on outcomes related to brain health. The evidence supports that gardening is a low-to-moderate physical activity likened to aerobic exercise [24] that has the potential to stimulate neuroplasticity and improve cognitive health. This is important evidence since engaging in physical activities of gardening requires bodily movement that is produced by the contraction of skeletal muscle and thus results in energy expenditure and increases the expression of VEGF cell signaling [36, 61]. Thus, gardening, like other forms of low-to-moderate intensity exercise, can operate as a physical activity that increases the availability of endogenous neurotrophic factors and PDGF, and by implication enhances neuroprotection and neurorestorative effects of the brain [62]. Based on existing research, peripherally generated BDNF can serve as a metabolite in response to skeletal contraction and cross the blood-brain barrier, promoting activation in the central nervous system [63]. For instance, Park and colleagues [36] provided evidence for this claim when they found a significant increase in brain nerve growth factor levels following low-to-moderate-intensity physical activity in gardening, which was linked to improved memory. Although intensity and duration in the protocol of gardening activity differ across studies in this review, there is emerging evidence for the benefit of gardening in increasing the expression of brain growth factors for neuronal survival and cognitive function. Furthermore, the fact that multiple studies found a significant decrease in plasma IL-6 levels during and after engaging in gardening physical activity is also important because elevated levels of IL-6 have been associated with a higher risk of dementia, depression, anxiety, and problems with encoding and recall memory [64]. This finding together with increased levels of BDNF reinforces the beneficial role of gardening physical activity to promote neuroplasticity, enhance cognitive function, and improve psychological health. Although there are only a small number of studies, the findings are nevertheless encouraging. Especially, since the existing research has linked the role of BDNF in synaptic plasticity and reduced risk of neurodegenerative pathologies [23, 65]. One of the main limitations of these findings is that none of the studies used longitudinal designs with appropriate controls that could be followed for an extended period beyond the respective interventions. This makes it difficult to determine the possible long-term benefits of the intervention and limits the empirical interpretation and therapeutic usefulness of the findings. One way to address these limitations is by conducting better study designs. These should be adequately powered, with active control groups to mitigate the placebo effect and ensure statistical validity.

Some of the research showed that gardening physical activity was associated with the modulation and regulation of neuro- and cardio-physiological responses in humans that correlated with noticeable benefits in cognitive and emotional health. The findings from these EEG and neurophysiology output studies provided evidence of physical activity involved in gardening and its instantaneous benefits on brain health (e.g., improving attention and regulating cortisol levels for mood improvement), at least within the quasi-experimental context. Moreover, the emerging fMRI and fNIRS literature on the physical effect of certain gardening tasks (e.g., seeding, weeding, plowing, etc.) on activating important brain areas responsible for attention, concentration, and executive-higher-order cognitive function, reinforces its role in enhancing neuronal and synaptic plasticity [29]. To this end, these findings hint at how regular gardening activities might turn into a helpful tool in the fight against premature cognitive decline and other forms of dementia by showing that during gardening activity, specific tasks, like digging, ranking, and pruning are particularly good at inducing persistent activation in particular brain regions involved in memory, learning, executive function, and emotional processing [46]. However, the extent to which these findings can be observed in a therapeutic context remains to be investigated.

In this review, the MMSE was the most used screening tool in studies evaluating cognitive function outcomes of gardening activities. The MMSE taps into orientation, memory, immediate, delayed, and recognition recall, attention, and position in time and space. Other cognitive tests used in studies included the verbal learning test (memory), TMT-A (visual scanning, motor speed skills) and B (cognitive flexibility), Wechsler Memory Scale-Revised, word-list memory tasks, WAIS-III-digit span (attention span), and WAIS-III-digit symbol substitution test (processing speed, working memory, visuospatial processing, attention). If anything, this highlighted the need for the inclusion of more comprehensive and reliable neuropsychological measures of cognitive function. A critical area for future studies is the inclusion of a comprehensive battery of neuropsychological tests in conjunction with neuroimaging and neurophysiological measures. Correlating neuropsychological testing with neuroimaging and neurophysiological data can strengthen the findings associated with neurological gains of gardening as a healthful physical activity. This would provide a persuasive encouragement to governments and policymakers to consider gardening physical activity as a beneficial health intervention to be incorporated into healthcare.

The studies cited in this review support the notion that engaging in certain gardening-related activities has favorable effects on neurophysiological alterations that are beneficial for psychological and neuropsychiatric health. The strength of these results is that, unlike self-reported assessments, they are supported by objective neurophysiological, EEG, and neuroimaging data. Even though there have only been a few studies done so far, the studies in this review showed that gardening can help people feel less stressed, anxious, and depressed. The emerging evidence supporting the benefits of gardening includes increased blood flow to the brain, synaptic and neuronal stimulation. Vance and colleagues [66] showed that sensory experiences such as touching the soil and smelling plants can stimulate the brain, which can increase synaptic plasticity and promote overall brain health. This evidence supports the benefits of olfactory training for brain health. Other studies have demonstrated that this kind of training can improve functional connectivity between the olfactory bulb and hippocampus, leading to enhanced global cognition. Together, the research findings support gardening as a possible valuable resource for health promotion and prevention by offering some emerging evidence of its restorative effects.

Limitations

The findings of this study have some limitations to consider and must be interpreted in that context. The present review covers a limited number of published articles. This limited number of studies that used the physical activity of gardening as an intervention approach suggests that the ground for innovation, validation, feasibility, and clinical transfer in the management of cognitive disorders and neurodegenerative diseases is promising. This synthesis of evidence is by no means inferring any causal relationship. The major limitation of a narrative synthesis is that the focus is not on quantitative synthesis and thus effect size of the intervention was not the objective of this study. The included studies were based on a specified and restricted inclusion criterion that potentially biased other studies. Also, there is a degree of bias within this review by only including studies conducted in English that were accessible in the public domain; and possible publication bias, given that only published articles were included. Additionally, no studies on the subject were found to have been carried out in Africa, which emphasizes the significance of this topic's research in a developing context. Based on the findings of this review, gardening can promote brain health and overall well-being. Still, more research is needed to fully understand the underlying mechanisms of gardening's physical activity and whether the effect continuation is long-term observable. This will help determine whether gardening can be regarded as a plausible therapeutic intervention.

Conclusion

According to the results of this narrative synthesis, physical activity through gardening has the potential to benefit brain health. Albeit the small number of studies, the evidence seems to suggest that the physical activity involved in gardening can increase the availability of nerve growth factors like BDNF, VEGF, and PDGF. Several studies that used fMRI, fNIRs, and EEG techniques included in this review provided some evidence that certain gardening tasks can be effective in activating functional connectivity in the brain and increase cerebral oxygenated blood flow in core brain structures involved in learning, memory, and executive function, at least within the experimental context. Similarly, engaging in certain tasks of gardening such as having contact with the soil through digging and planting was found to increase neurotransmitters (serotonin, dopamine) and regulate inflammatory cytokines (IL-6, IL-2), which in turn helped with improving anxiety and depressed mood. The included studies have a major limitation due to the lack of well-randomized controlled and longitudinal study designs. To conclude, the effectiveness of gardening-related physical activities on brain health may depend on factors such as the age of the participants, the external environment of the activities, the duration and the type of gardening activities participants perform, and the presence or absence of a cognitive disorder. Randomized controlled study designs that included neuropsychological testing, blood, and imaging biomarkers are potential ways of effectively measuring and better understanding the beneficial mechanism of gardening as a physical activity.

Implication

A key feature for future research will be to use diverse research designs, as well as neuroscience techniques like wearable (portable) fNIRS, EEG, fMRIs blood biomarkers, and standardized neuropsychological testing. There is also a need for standardized gardening physical activity intervention to minimize heterogeneity across studies. Uncovering the underlying neurophysiological mechanism of physical activity in gardening in terms of dose (duration, frequency, and intensity) and how it correlates with cognition is critical to the advancement of studies of neurorehabilitation and neurodegeneration. It would perhaps be helpful for a task force to form and investigate the issue of standardization, accurate and consistent data collection and sharing.

Given the health benefits associated with gardening physical activity that were shown in the few studies included in this review, we should view it as a significant and potential health resource for the local community. Despite the limitations, the emerging results are encouraging because they imply that gardening can be used as a physical activity to help people lower their risk of cognitive decline, neurobehavioral problems, and perhaps even dementia.

Cognitive interventions are the most effective way to reduce the risk of central nervous system damage and enhance the quality of life for people with neurodegenerative disease and risk for neurological damage. However, the high cost of most cognitive rehabilitation and psychopharmacology makes it hard for deserving patients in low-middle income countries, including South Africa to receive the benefits of neuroscience advances.

The benefits of gardening as a physical activity in contexts with limited resources seem as a viable and feasible alternative intervention to improve cognitive health. In addition to being cost-effective, it can also be very accessible, in that patients can simply incorporate it into their daily lives, minimizing the need for additional burdens and running a low risk of complications. While there is still limited research on the health benefits of gardening for people undergoing neurotoxic treatment for cancer, there is evidence from other neurodegenerative diseases (Alzheimer's, Parkinson's disease, stroke, neuropsychiatry, etc.) that it may help preserve, restore, and improve cognitive function in disease states.

Abbreviations

AD: Alzheimer's disease

BDNF: brain-derived neurotrophic factor

EEG: electroencephalography

fMRI: functional magnetic resonance imaging

fNIRS: functional near-infrared spectroscopy

IL-6: interleukin-6

MMSE: Mini-Mental Status Examination

PDGF: platelet-derived growth factor

PFC: prefrontal cortex

RCTs: randomized controlled trials

TMT: trail making test

VEGF: vascular endothelial growth factor

WAIS-III: Wechsler Adult Intelligence Scale, Third Edition

Supplementary materials

The supplementary materials for this article are available at: https://www.explorationpub.com/uploads/Article/file/100481_sup_1.pdf

Declarations

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Author contributions

AGL: Conceptualization, Data curation, Formal analysis, Writing—original draft, Writing—review & editing.

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The author declares that he has no conflicts of interest.

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Consent to participate

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Availability of data and materials

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