

Go for the Mind: A Review of Go's Cognitive Benefits for the Young and Old

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Introduction

The purpose of this review is twofold. First, it synthesizes existing research on the relationship between the abstract strategy board game of Go and cognition, with a particular focus on how Go may support cognitive development in children and help maintain cognitive functioning in older adults. Second, it explores the broader implications of these findings for future cross-disciplinary research, highlighting how Go can be more fully leveraged as an educational tool to support children's cognitive development and help older adults maintain cognitive function across the lifespan.

The call for this review comes at a timely moment. In a culture dominated by video games, board games have experienced a resurgence, driven by perceived factors such as digital fatigue, affordability, entertainment value, and their capacity to engage cognitive processes (Bayeck, 2020; Donovan, 2017). At the same time, advancements in neuroscience during the late 1990s and early 2000s—often called the “neuroimaging boom” (Raichle, 2009; Van Horn & Toga, 2014)—have made studying the relationship between Go gameplay and cognition increasingly feasible. Although relatively few studies have examined the relationship between cognition and the game of Go, recent literature indicates that Go has garnered increasing attention in the field of neuroscience over the past decade.

Interest in Go has also been boosted by advances in artificial intelligence. In 2016, AlphaGo, a Go computer program developed by Google DeepMind, defeated world champion

Lee Sedol. The match highlighted the game's strategic depth and demonstrated AI's ability to learn complex decision-making. This milestone brought global attention to the game of Go, which has simple rules but an extraordinary complexity, with over 10^{170} possible board configurations—more than the number of atoms in the known universe (Tromp, n.d.). It may also have sparked research interest in the cognitive demands Go places on players and its value as a rich context for studying cognition in both natural and AI-enhanced settings.

Focusing on cognition in both youth and older adults addresses critical periods of cognitive vulnerability and growth. Supporting cognitive development in children lays the foundation for lifelong learning, while promoting cognitive health in older adults is increasingly important for maintaining independence and quality of life in an aging society.

Go Game: A Brief Overview

Go (also known as Baduk in Korea, Weiqi in China, and Igo in Japan) is a strategic board game originating in China over 3000 years ago. At least 60 million people play Go—primarily in East Asia—and more than 70 countries have official Go organizations (<https://www.britgo.org/press/faq.html>). The game has gained increasing popularity in the United States and Europe (Noda, 2019). Go is played on a standard 19-by-19 grid board with 361 intersection points. To accommodate beginners, smaller boards—such as 6-by-6 for teaching demonstrations and introductory play, and 7-by-7 boards for skill development—are often used.

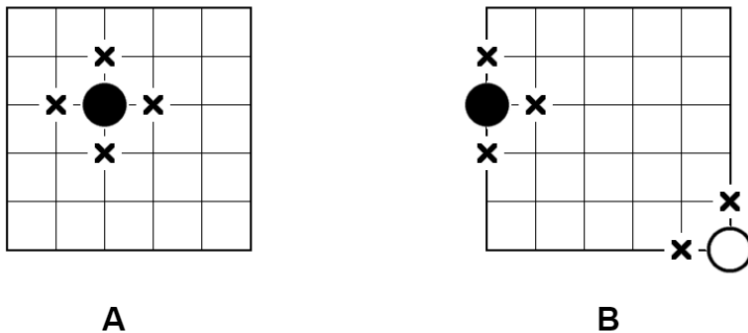
Go is a two-player game in which players take turns placing black and white stones on vacant intersections. The objective is to control the most territory on the board, unlike chess, where the goal is to checkmate the opponent's King. Go stands out among strategic board games due to its unique combination of simplicity in rules and depth in play, which require sustained

attention, spatial reasoning, number sense, and flexible problem-solving. Go's simple and intuitive rules make it accessible to children and players of all levels.

Beginners are often taught three basic concepts and rules as an introduction to Go. The first is *Qi* (also spelled *Chi*), or liberty, which refers to the empty points directly adjacent to a stone in the four cardinal directions. A stone's *Qi* represents its available "breathing spaces" and determines whether it can survive on the board. Figure 1 illustrates the number of *Qi* available to a black stone placed in the middle, on the edge, or in the corner of the board. When a stone, or a connected group of stones, runs out of *Qi*—meaning it is completely surrounded orthogonally by the opponent's stones—it is considered captured and must be immediately removed from the board.

Figure 1

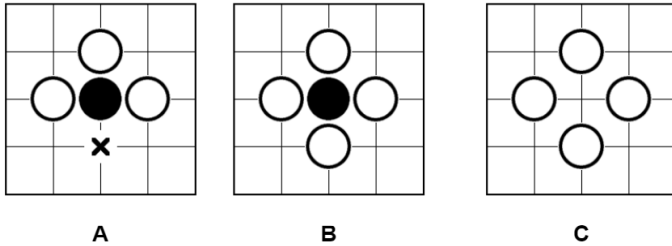
Concept of Qi (Liberty)



The second concept is capture. When a stone or group of connected stones has only one liberty remaining, it is in "red alert" because the opponent can place a stone on that final liberty to capture them. The image in Figure 2 shows how white stones, once completely surrounded and deprived of their last *Qi*, are captured and immediately removed from the board.

Figure 2

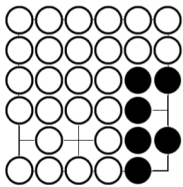
Steps of Capture



The third concept is “two eyes”, which ensures stones are safe from capture. a group of stones with two eyes cannot be captured and is guaranteed to survive. In Figure 3, both the black and white groups have formed two eyes, allowing them to remain safely on the board when both players pass to end the game.

Figure 3

Guaranteed Survival with Two Eyes



This literature review addresses two primary questions: 1) What are the major studies that have examined the relationship between Go gameplay and cognitive development in children or cognitive maintenance in older adults? 2) What cognitive benefits of Go gameplay are reported in the studies reviewed?

Review Methods

Guided by the central questions, I conducted an iterative review of research published from 2000 to the present. Unsurprisingly, many of the studies selected involved neuroimaging methods, reflecting both the rapid advancements in neuroscience during this period and the field's growing application to areas such as education and cognitive training. This section outlines the procedures and methods used in conducting the review.

Literature Search Process

Twelve rounds of searches were conducted, with each round informing and refining the next. Searches were carried out using EBSCOhost, Academic Search Complete, Google Scholar, and Google. EBSCOhost provides access to multiple electronic databases, including Academic Search Complete—a multidisciplinary database offering full-text access to over 5,300 periodicals, including 4,400 peer-reviewed journals, along with abstracts and indexing for a broad range of scholarly publications. To capture all relevant literature, the search employed a range of keywords and phrases, including: *Mind sports and cognition*; *Board game(s)*; *Go and Weiqi and cognitive*; *Baduk*; *Go (Game) and cognitive*, “*Go game*” and *cognitive development*, “*Weiqi AND cognition*”, “*Weiqi*”, *cognition, children*, “*Go game*” AND “*Learning*” AND “*Schools*”, “*Go game*”, “*cognitive development*”, “*Go game*”, and “*executive function*”.

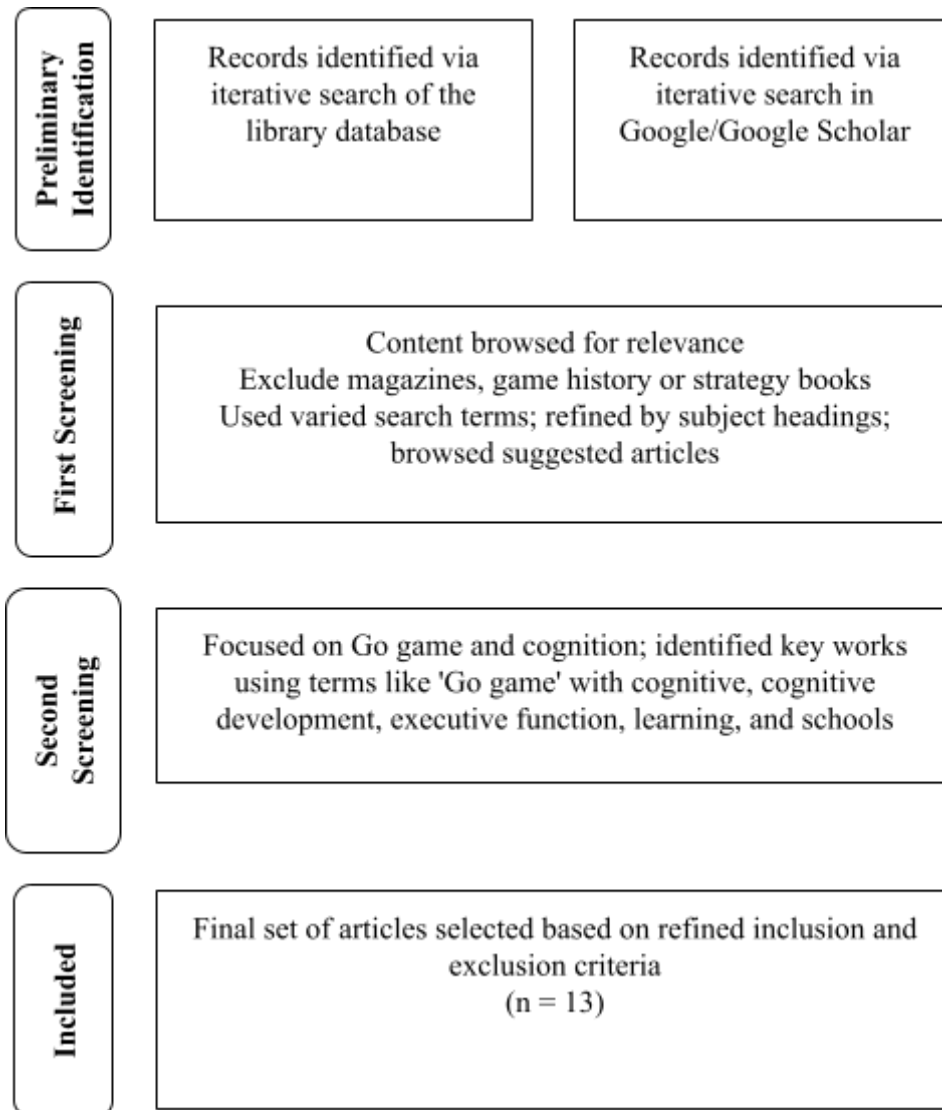
The initial search, using broad keywords such as “mind sports and cognition” and “board games,” yielded approximately 3,860 results. The term “board game” alone produced 2,845 hits, though most were unrelated to traditional board games like Go. In each search round, I reviewed titles and abstracts to make an initial judgment of relevance—an approach shown to reduce error and minimize bias in inclusion decisions (Chander et al., 2013; Atkinson et al., 2014). This

helped determine whether a source should proceed to the next stage based on alignment with the review's focus.

Over 12 iterative rounds, I recorded potentially relevant sources and, when necessary, examined abstracts or skimmed full texts to assess their fit. After each round, I revised search terms using subject headings and keywords suggested by prior results. This iterative approach supported the development of clear inclusion and exclusion criteria, ensuring transparency and a well-defined scope for the review (Nightingale, 2009; Page et al., 2021). Figure 4 presents a flow diagram of the study selection process.

Figure 4

Flow Diagram of the Study Selection Process



Inclusion and Exclusion Criteria

Clear inclusion and exclusion criteria are essential to the systematic review process. They help reviewers calibrate the scope of the review to align with its aims and reduce bias in study selection (Booth., 2016; Gough et al., 2017). Initial exploratory searches often reveal variations

in terminology, recurring themes, and patterns of irrelevant results, which inform the iterative refinement of these criteria. As Arksey and O'Malley (2005) note, such iterative adjustment is especially important in scoping reviews. Practical considerations—such as language (e.g., English only), publication date, and access to full texts—also shape the criteria, helping to ensure the review remains focused and feasible.

This review includes studies published from 2000 to the present, a period marked by significant advances in neuroscience and growing interdisciplinary interest in cognition and learning. This timeframe emerged naturally from the literature, as research linking Go and cognition began to appear more prominently during this period.

Only English-language publications were included, but the selected studies represent research conducted by scholars from various countries, including the United States, France, Japan, Korea, China, and Switzerland.

The review focused specifically on studies in which Go was the primary intervention or activity influencing cognitive functions, while excluding those involving video games, commercial board games, or educational “serious games.” Studies centered on professional Go training were also excluded, as they primarily treated Go as a competitive mind sport or examined structural brain differences between amateurs and professionals. However, I reviewed these articles for relevant insights, noting that sustained Go training has been linked to enhanced brain network integration and improvements in cognitive functions such as spatial perception, attention, working memory, executive control, and problem-solving.

Studies were included if they targeted populations such as children, seniors, or novice and amateur Go players, as these groups align with the review's emphasis on cognitive development and maintenance across the lifespan. In fact, only one study was found that focused on

participants between childhood and older adulthood (ages between children and those over 65). Studies that focused solely on professional Go players or expert-level performance were excluded, especially those centered on the path to expertise or grounded in intelligence theories.

Qualitative and quantitative studies, as well as review articles and neuroimaging research, were included if they reported findings on Go gameplay and its impact on participants' cognitive functions. Studies with incomplete results or no reported outcomes were excluded from the analysis. All articles included in the review were published in peer-reviewed academic journals. Unsurprisingly, most of these journals fall within the fields of medicine, neuroscience, gerontology, and geriatrics. The major journals represented are listed below:

- Aging Clinical and Experimental Research
- American Journal of Alzheimer's Disease & Other Dementias
- BioPsychoSocial Medicine
- Brain and Behavior
- Brain Research
- Frontiers in Aging Neuroscience
- Games for Health Journal
- Geriatrics & Gerontology International
- International Journal of Geriatric Psychiatry
- Journal of Alzheimer's Disease
- Journal of Mathematical Behavior
- Psychiatry Investigation (Publisher: Korean Neuropsychiatric Association)

Table 1 below presents an overview of the characteristics and key findings of the included studies, organized by lead author, year of publication, title, main focus, methodology,

participants, primary data/outcome measures, setting, and key findings. A total of 13 sources were included in this literature review, comprising 5 review articles and 8 empirical studies on Go and cognitive function. Of the 8 studies, 3 were qualitative studies involving children, and 5 were quantitative intervention studies focused on older adults (65+).

Table 1

Overview of the Included Studies

Articles (Years)	Main Focus	Participants	Methodology	Primary Data/ Outcome Measures	Key Findings
Noda, S. et al. (2019). The effectiveness of intervention with board games: a systematic review.	Effectiveness of board games and programs that use board games on educational knowledge, cognitive functions, and other conditions	Elementary students (aged 6+) and adults, including elderly with diverse health conditions	Systematic Review	Cognitive function and skills	Go improved attention and working memory in older adults with cognitive decline. Chess enhanced math and metacognitive skills in children. Go also improved ADHD symptoms.
Nakao, M. (2019). Special series on "effects of board games on health education and promotion" board games as a promising tool for health promotion: a review of recent literature.	How playing board games may support psychosomatic health	From children to elderly; novices to expert board gamers; with/without medical or psychological conditions	Systematic Review	fMRI and EEG; Cognitive function measurements (memory, attention, executive function, etc.)	Go studies in this review found symptom improvement and BDNF upregulation in Alzheimer's patients. Additionally, board games like Go are suggested as preventive and therapeutic tools for cognitive-behavioral conditions such as ADHD and dementia.
Lizuka et al. (2019). Can cognitive leisure activity prevent cognitive decline in older adults? A systematic review of intervention studies.	Systematic review of intervention studies of cognitive leisure activities for older adults and their effects on cognitive functions	Older adults (aged 60+) who were healthy or had dementia or mild cognitive impairment, including community-dwelling and institutionalized older adults.	Systematic Review	Global cognition and specific cognitive domain measures (e.g., executive function, memory, attention, verbal function, processing speed, visuospatial cognition)	Cognitive leisure activities can enhance cognitive function in older adults, especially those involving new skill learning, intellectual stimulation, and communication. Learning Go supports cognition, even in individuals with cognitive decline.

Chen, P. J. (2022) Effects of tabletop games on cognition in older adults: A systematic review and meta-analysis.	Effects of tabletop games on global cognition and domain-specific functions (attention, memory, executive function, verbal fluency) in older adults.	Adults (mean age 67+) in long-term care, community, or daycare, with cognitive impairments or intact cognition	Systematic Review	Global cognition and specific cognitive domain measures (e.g., executive function, memory, attention, verbal fluency, etc.)	Both older adults with intact cognition and those with mild cognitive impairment or dementia showed cognitive improvements after tabletop game interventions. Tabletop games improved executive function in cognitively intact older adults.
Pozzi, F. E., et al. (2023). Can traditional board games prevent or slow down cognitive impairment? A systematic review and meta-analysis.	Impact of traditional board games on cognitive decline in the elderly	Elderly (aged 60+) in nursing homes, hospitals, community, or day care with cognitive impairment, and cognitively impaired patients of any age	Systematic Review/Meta-analysis	Global cognition and specific cognitive domain measures (e.g., executive function, memory, attention, verbal fluency, etc.)	Go may boost visual and working memory and strengthen brain activity and connectivity related to cognition.
Lin et al. (2015). The impacts of a GO-game (Chinese chess) intervention on Alzheimer disease in a Northeast Chinese population.	Brain derived neurotrophic factor (BDNF) is often deficient in AD patients. This study explored the effect of Go game in AD patients on the levels of BDNF in AD patients before and after the study.	Patients with Alzheimer's disease (AD) in hospital, with no previous experience of Go	Quantitative Intervention Research	Biomarker lab test to quantify serum brain-derived neurotrophic factor (BDNF); Neuropsychological tests	After the Go intervention, participants showed increased serum BDNF, a key protein for learning and memory. They also experienced reduced depressive symptoms and improved quality of life.
Lizuka et al. (2018). Pilot randomized controlled trial of the GO game intervention on cognitive function.	Effects of an intervention using Go on cognitive function in nursing home residents	Adults (aged 65 +) with cognitive decline in nursing homes	Quantitative Intervention Research	Global cognition and specific cognitive measures (e.g., attention, working memory, and short-term memory)	Go intervention improved attention and working memory in participants, whereas these functions declined in the control group. All participants, even with moderate dementia, learned Go rules; those with milder impairment played successfully.
Lizuka et al. (2019). Does social interaction influence the effect of cognitive intervention program? A	Impact of a Go intervention on cognitive function in older adults, focusing on isolating social interaction effects from gameplay	Adults (aged 65 +) without Go experience, independent in daily living	Quantitative Intervention Research/RCT	Specific cognitive measures: working memory (visual and verbal); verbal function; executive function	Playing Go may enhance visual working memory in community-dwelling older adults, independent of social interaction. However, greater cognitive gains in the face-to-face group suggest that social interaction amplifies the benefits of gameplay.

randomized controlled trial using Go game.

Lizuka et al. (2020). Neural substrate of a cognitive intervention program using Go game: a positron emission tomography study.	Brain activity changes from a Go-based cognitive intervention: relationship between brain activity and acquisition of Go skills	Adults (aged 65 +) without Go experience, independent in daily living, no history of diagnosis of dementia	Quantitative Intervention Research/ RCT	Neuroimaging/ PET scan image; cognitive function tests (visual memory span; digital span; verbal fluency; logical memory; MMSE-J)	Playing Go was associated with increased activity in cognitive-related regions—left middle temporal gyrus, bilateral putamen, and left frontal lobe (intervention group only)—alongside improved logical memory (LMII)..
Lizuka et al. (2024). “GO” to move toward dementia-friendly communities: A pilot study	Feasibility and potential benefits of a peer-led Go program	Community-dwelling adults (aged 65+) with cognitive decline	Quasi-experimental design	Pre- and post-cognitive function tests and individual interviews	Go beginners showed no significant cognitive gains but reported emotional and social benefits. Supporters demonstrated improved global cognition.
Kim, et al. (2014). Baduk (the Game of Go) Improved Cognitive Function and Brain Activity in Children with Attention Deficit Hyperactivity Disorder	Effects of playing Go on cognitive functions, with a focus on executive function and prefrontal EEG activity in children with ADHD	Children aged 7 to 12 years old, with no experience playing Go	Quantitative Intervention Research	Specific cognitive measures (working memory, attention, executive functioning); EEG; ADHD Rating Scale (ARS)	Over 16 weeks of Go training, children with ADHD showed reduced inattention scores and improved brainwave patterns linked to attention. They also demonstrated gains in executive function, verbal working memory, visuoperceptual skills, cognitive flexibility, and persistence. These results suggest Go as a promising complementary therapy for ADHD.
McFeetors, P. J., & Palfy, K. (2018). Educative experiences in a games context: Supporting emerging reasoning in elementary school mathematics.	Elementary students’ development of reasoning using abstract strategy games, including Go	Grades 5 and 6 students	Qualitative Research	Field notes; photos of game board configurations during games that showed strategic thinking; recordings of students’ oral descriptions of strategies; student interviews; teacher interviews; record sheets; pedagogical	The absence of chance in abstract strategy games like Go compels students to construct reasoned moves and strategies, recognizing the inherent logical thinking as valuable. The authenticity of games fosters collaborative play that develops mathematical reasoning through representing, conjecturing, convincing, and justifying.

<p>Yu, Y. (2021). <i>Spatial Thinking and the Learning of Mathematics in the Game of Go</i>. [Unpublished doctoral dissertation]. Northwestern University.</p>	<p>Unpack aspects of mathematics embedded in learning and playing Go and demonstrate how playing Go can facilitate the development of spatial and mathematical thinking through mapping of numbers to space and spatial visualization, grounding numerical and arithmetic concepts in spatial forms, in a Go and math curriculum designed specifically to teach young children how to play Go, while fostering spatial and math skills at the same time.</p>	<p>Students in grades 2 and 3, aged 7 to 9 years old</p>	<p>Qualitative Research</p>	<p>processes</p> <p>Pre- and post-assessment of students' spatial thinking and pattern recognition; Mental Rotation Task; Corsi Blocks; spatial working memory test; Observations; Videos of teaching and Go game play; Student interview</p>	<p>Findings showed that children in Grades 2–3 engaged in core practices such as conjecturing, justifying, and generalizing through spatial reasoning activities embedded in the game. Playing Go had no significant effect on mental rotation tasks. However, the game's spatial structures—such as dynamic patterns and board-based number representations—supported flexible thinking and conceptual progression. These spatial elements aligned with key math concepts, helping students deepen and extend their understanding of number, operations, and early algebra. Score-counting activities encouraged problem-solving and the emergence of multiplicative strategies.</p>
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Findings

This section synthesizes the relationship between board games in general and the game of Go in particular in supporting cognitive functions in youth and older adults, based on 14 selected sources. It begins with four review articles featuring “board games” in their titles, as they examine a range of board games, including Go. The synthesis then turns to the remaining studies that focus exclusively on Go and its specific cognitive effects.

Findings from Review Articles

This section begins with a discussion of the five review articles included in this paper (see Table 1), and then transitions to the findings from the individual empirical studies. The review articles are organized from broad to specific: the first two examine a wide age range—from elementary-aged children to older adults—and explore the cognitive effects of various board games, including Go. The remaining three reviews are grouped together, as they focus specifically on older adults and the potential of Go and other traditional board games to support cognitive functioning in the context of cognitive decline or dementia.

Noda et al. (2019): Systematic Review on Board Game Interventions

Noda et al. (2019) conducted a systematic review examining the effects of board games and related programs on educational knowledge, cognitive functions, and conditions such as physical activity, anxiety, Attention Deficit Hyperactivity Disorder (ADHD) symptoms, and Alzheimer’s disease. They defined board games broadly as games involving the placement, movement, or removal of pieces on a patterned board, following specific rules of movement. Most of the games included were educationally themed—focusing on topics like health, safety, and lifestyle—which fall outside the scope of the present review. For cognitive functions

specifically, they analyzed 11 studies that examined the effects of board games, including the traditional Thai game "Ska" and the abstract strategy games chess and Go. Chess was the most commonly studied game in the body of research reviewed by Noda et al.

Three studies included in Noda et al.'s review investigated cognitive functions in relation to Go: one compared chess and Go (Sala & Gobet, 2016), and two focused solely on Go (Lin et al., 2015; Iizuka et al., 2018). In the study by Sala and Gobet, 52 fourth-grade students were randomly assigned to a chess intervention group, an active control group receiving Go lessons, and a passive control group with regular school activities only. The chess intervention group received 15 hours of chess lessons during school hours in addition to regular instruction. The active control group received 15 hours of Go lessons, while the passive control group participated in regular instruction only. Results showed no statistically significant differences among the groups in mathematical problem-solving or metacognitive ability as measured by a questionnaire.

In Lin et al. (2015), researchers investigated the effects of Go gameplay on patients with Alzheimer's disease (AD), who were randomly assigned to two intervention groups (one-hour and two-hour daily sessions) or a control group. They measured serum levels of brain-derived neurotrophic factor (BDNF)—a protein essential for neuron growth and survival—before and after the six-month intervention. Low BDNF is associated with conditions such as depression and Alzheimer's. After the intervention, both Go groups showed significantly higher serum protein levels of BDNF compared to the control group. In addition, the severity of AD symptoms decreased significantly in the Go groups, suggesting that regular Go play may support cognitive and emotional functioning in individuals with AD.

Lizuka et al. (2018) conducted a randomized controlled trial to examine the effects of Go intervention on cognitive function in older adults. Participants in the intervention group attended 15 weekly one-hour sessions that included instruction, problem-solving, and gameplay, while the control group received usual care. Results showed significant improvements in attention and working memory in the intervention group, while the control group showed declines.

Noda et al. also included a study on ADHD by Kim et al. (2014), which found significant reductions in ADHD symptom severity among children. The study reported improvements in cognitive flexibility and persistence, along with greater changes in theta/beta activity in the right prefrontal cortex over 16 weeks compared to the control group.

Nakao, M. (2019): Effects of Board Games on Health Education and Promotion

This review explores the educational and health effects of board games, including seven studies related to Go and cognition. Two previously discussed studies are included: Lin et al. (2015), which found that Go alleviated Alzheimer's symptoms by increasing BDNF levels, and Kim et al. (2014), which reported reduced ADHD symptoms after a 16-week Go intervention. In Kim et al.'s study, QEEG results showed improved prefrontal brain activity, including decreased theta/alpha and theta/beta ratios—patterns associated with inattention and executive dysfunction. The reduction in the theta/beta ratio in the right prefrontal cortex was particularly significant compared to the control group.

The remaining five studies in Nakao's review involve participants with medical conditions unrelated to cognitive decline (e.g., epilepsy) or focus on expert Go players, and therefore fall outside the scope of my review, which centers on cognitive development in youth

and cognitive maintenance in older adults. For this reason, these studies are not included in the detailed reporting of findings in the current review.

Three Reviews on Go and Board Games for Cognitive Decline in Older Adults

The remaining three review articles focus on the role of games, including Go, in supporting cognitive functions and helping to prevent cognitive decline among older adults. The review article by Lizuka et al. (2019) seeks to identify leisure activities that can enhance cognitive function or delay cognitive decline in both healthy older adults and those with dementia or mild cognitive impairment. Of the 20 studies reviewed, only three involved board games—two on mahjong and one on Go. All three studies reported intervention effects on cognitive function. The Go study showed improvements in attention and working memory, indicating that learning new Go skills can support cognitive function even in individuals with cognitive decline. Across studies with positive outcomes, three features were common: activities provided greater intellectual stimulation than daily routines, required learning new skills, and included social interaction. These interventions produced broad cognitive benefits, including improvements in working memory.

The other two review articles are Pozzi et al. (2023), which examined traditional abstract board games and their roles in slowing cognitive decline in elderly at risk or already suffering from cognitive decline or dementia, and Chen et al. (2022), which explored the effects of tabletop games on cognition in older adults. Their findings are highlighted below.

Pozzi et al. (2023) defined traditional board games like chess and Go as “games of skill” that engage multiple cognitive domains, in contrast to games of chance. These traditional games are widely accessible, and often supported by active communities. Their meta-analyses examined

15 studies on the effects of such games—specifically chess, Go, mahjong, and ska—on cognitive decline in older adults. Four of the reviewed studies focused on Go. The results suggest that traditional board games are promising cognitive interventions for preventing dementia and slowing cognitive decline. They improve mental functions after 3 to 4 months of intervention. Different games appear to target distinct cognitive domains: Go and Ska improve attention, while mahjong shows potential for enhancing executive function. The lack of Go’s effect on executive function may be due to short intervention duration or insufficient intensity.

The review by Chen et al. (2022) is a meta-analysis examining the effects of tabletop games on global cognition and specific cognitive domains—such as attention, memory, executive function, and verbal fluency—in older adults. Defined as cognitive leisure activities that involve rules, strategic movement of pieces, and the use of memory, planning, and calculation, tabletop games like Go and chess were found to stimulate both cognitive functions and interpersonal interactions. The analysis showed that these games can enhance overall cognitive performance and working memory, regardless of participants’ cognitive status. Notably, Go-based interventions led to improvements even among older adults with mild cognitive impairment or dementia, suggesting that structured gameplay can remain accessible and beneficial even for those experiencing cognitive decline.

Overall, the five review articles discussed above demonstrate positive effects of board games in general and Go in particular on cognitive functions and abilities in both children, including those with ADHD, and older adults regardless of cognitive decline status. While two reviews included broader age groups and a variety of games, three focused on older adults experiencing cognitive decline. Across these reviews, Go was associated with cognitive benefits including improved attention, working memory, and global cognition. One review also reported a

study showing that Go interventions reduced ADHD symptoms in children and produced changes in brainwave patterns associated with improved executive function. Studies with older adults experiencing mild cognitive impairment or dementia found that participants could learn and benefit from playing Go, showing improvements in cognitive functions. The rules of Go are simple and easy for beginners to grasp, while its complexity keeps players interested throughout interventions. These findings suggest Go's promise as a cognitively stimulating activity for both cognitive development and maintenance.

Findings from Individual Empirical Studies Included in the Review

This section presents findings from eight individual studies exploring the relationship between Go and cognition. The studies are organized into two groups: those involving older adults (see Table 2) and those involving children (see Table 3). All five studies with older adults are quantitative interventions; four are randomized controlled trials (Lin et al., 2015; Iizuka et al., 2018, 2019, 2020) featuring Go-based interventions compared to active control groups. These studies measured cognitive outcomes, including global cognitive function and specific domains such as memory, attention, and executive function. Table 3 summarizes three studies on children's cognitive development: one quantitative intervention with children diagnosed with ADHD (Kim et al., 2014), and two qualitative, classroom-based studies examining how Go and tailored instruction support mathematical reasoning and skill development (McFeetors & Palfy, 2018; Yu, 2021).

Table 2

Individual Studies on Go and Cognition in Older Adults

Articles (Years)	Methodology	Participants	Intervention	Primary Cognitive and Related Outcome Measures	Go Effects on Cognition
Lin et al. (2015)	Quantitative Intervention Research/RCT	Patients with Alzheimer's disease (AD) in hospital, with no previous experience of Go (n=147)	147 AD patients with no prior Go experience were enrolled in a 6-month randomized controlled trial across three groups: control (n=49), short-time Go intervention (1 hour daily, n=49), and long-time Go intervention (2 hours daily, n=49). Go groups learned the rules online and received coaching from a player. Participants played in randomly paired matches or, if no partner was available, played against staff or observed games.	Biomarker lab test to quantify serum brain-derived neurotrophic factor (BDNF); Neuropsychological tests	A six-month Go game intervention significantly reduced depressive symptoms and improved quality of life in patients with Alzheimer's Disease (AD). Participants also showed increased serum BDNF levels—a protein essential for learning and memory—indicating a potential biological mechanism underlying the observed benefits. These findings support Go as a promising, feasible, and non-pharmacological approach to slowing AD progression, alleviating depressive symptoms, and enhancing life quality of AD patients.
Lizuka et al. (2018).	Quantitative Intervention Research	Adults (aged 65 +) with cognitive decline in nursing homes	Participants were randomly assigned to a Go intervention (n=9) or control group (n=8). The 15-week intervention involved weekly 1-hour sessions at nursing homes, led by Go instructors. Each session included a rules lecture, exercises, and gameplay, with content adjusted to cognitive ability. Participants learned basic rules, with some progressing to advanced techniques.	Global cognition (MMSE & MoCA-J) and specific cognitive measures (e.g., attention, working memory, and short-term memory) Attention, working memory, and short-term memory tests (digit span forward and backward tasks)	The Go intervention significantly improved the total digit span score (a measure of attention and working memory) and maintained the digit span backward score in nursing home residents with mild to moderate dementia, while these scores declined in the control group. Notably, all participants, including those with moderate dementia, were able to learn the rules of Go, and those with milder cognitive impairment could play successfully.

Lizuka et al. (2019)	Quantitative Intervention Research/RCT	Healthy adults aged ≥ 65 years with no previous experience playing Go (community dwellers)	Participants were randomly assigned to one of three groups: a face-to-face Go group (FG, n=25), a non-face-to-face Go group (NFG, n=25), or an active control group (CG, n=22). FG participants attended twelve weekly in-person Go classes with instruction, gameplay and social interaction. NFG participants followed the same curriculum individually via tablet, without live interaction. CG participants attended monthly health lectures unrelated to Go.	Specific cognitive measures: working memory tests: Visual Memory Span Test (VMST); Digit Span Test (DST) Verbal function: logical memory (LM); Verbal fluency tests (logical memory and verbal fluency) Executive function: Trail Making Test (TMT)	Playing Go may enhance visual working memory in community-dwelling older adults, independent of social interaction. However, greater cognitive gains in the face-to-face group suggest that social interaction amplifies the benefits of gameplay.
Lizuka et al. (2020)	Neuroimaging/RCT	Adults (aged 65+) without Go experience, independent in daily living, no history of diagnosis of dementia	Participants were randomly assigned to an intervention group (IG; n=16) receiving 12 weekly 60-minute Go lessons, or a control group (CG; n=8) attending three monthly 120-minute health lectures.	PET scan image; cognitive function tests (visual memory span; digital span; verbal fluency; logical memory; MMSE-J)	Playing Go was linked to enhanced brain activity in regions related to cognitive functions, including the left middle temporal gyrus (semantic memory and cognitive control) and the bilateral putamen (reinforcement learning). Increased activation in the left frontal lobe was observed only in the intervention group, which also showed significant gains in logical memory performance (LMII).
Lizuka, et al. (2024)	Quantitative Intervention Study	Community-dwelling adults (aged 65+) with cognitive decline	Twelve weekly 60-min Go classes with lecture, exercises, and gameplay; beginners paired with supporters for in-class and weekly phone guidance; daily 10-min homework.	Pre- and post- cognitive function tests: Mini Mental State Examination-Japanese (MMSE-J) and Montreal Cognitive Assessment-J (MoCA-J); individual interviews	Go beginners showed no significant cognitive changes. Supporters demonstrated significant global cognition improvement, with MMSE-J scores improving post-intervention ($p < .05$).

Table 3

Individual Studies on Go and Cognition in Children

Articles (Years)	Methodology	Participants	Intervention	Primary Cognitive and Related Outcome Measures	Go Effects on Cognition
Kim, et al. (2014)	Quantitative Intervention Research	Children aged 7 to 12 years old, with no experience playing Go (n=34)	Seventeen children with ADHD and 17 control participants without ADHD took part in a 16-week Go training program, playing 2 hours/day, 5 days/week, with a Go instructor.	Specific cognitive measures: (memory, memory, and executive functioning: digit span test; Children's Color Trails Test [CCTT]); Quantitative Electroencephalography (QEEG) brain mapping; ADHD Rating Scale (ARS)	Over 16 weeks of Go training, children with ADHD in the intervention group showed reductions in ARS total and inattentive subscores, along with greater decreases in theta/alpha and theta/beta ratios—EEG markers linked to inattention and cognitive under-arousal. They also demonstrated improvements in executive function and attention. Digit Span Forward scores suggested enhanced verbal working memory, while Children's Color Trails Test (CCTT) results indicated gains in visuospatial skills, cognitive flexibility, and persistence. These findings support Go as a potential complementary intervention for improving core cognitive and attentional functions in children with ADHD.
McFeetors, P. J., & Palfy, K. (2018)	Qualitative Research/ Action research	Grades 5 and 6 students (n=45)	Three multi-age grade 5–6 classes participated in a year-long weekly program integrating strategy games to support mathematical reasoning. In Cycle 1, students played Gobblet Gobblers and Othello in pairs to develop and describe basic strategies. In Cycle 2, Go and Tic Tac Toe were introduced; students either advanced in their initial game or	Classroom field notes; photos of game board configurations during games that showed strategic thinking; recordings of students' oral descriptions of strategies; student interviews; teacher interviews; record sheets; pedagogical	Abstract strategy games like Go, absent from elements of chance, prompt students to construct purposeful, reasoned strategies, fostering an appreciation for logical thinking. Their interactive and authentic nature promotes collaborative play, where mathematical reasoning unfolds through representing, conjecturing, justifying, and convincing. With teacher scaffolding, students advanced from simpler games to Go, demonstrating increasingly sophisticated

			explored new ones, focusing on strategy refinement and justification. In Cycle 3, students refined and defended their chosen game strategies. Sessions ran 1 hr/week, led by a researcher with support from classroom teachers.	processes	reasoning and sustained engagement.
Yu, Y. (2021)	Qualitative Research	Students in grades 2–3 (Total N = 56) across three sites: Site A—an 8-week, 2-hour enrichment program (n = 5); Site B—a 10-week in-school Go class held once weekly across two combined classrooms (n = 44); and Site C—a 12-week, 1-hour weekend Go and math course (n = 7).	Examination of a Go and math curriculum specifically designed to teach young children how to play Go while simultaneously fostering their math skills, and of how the spatial features of Go and the spatial forms/shapes in instruction provided structures and support for children’s development of arithmetic understanding and mathematical reasoning practices	Pre- and post-tests of spatial thinking (2D Mental Rotation Task [MRT] and Corsi Block); classroom observations; pictures and videos for instruction and gameplay focusing on teacher actions, student-teacher and peer interactions; student exit group interview; math problem-solving worksheet with transfer problems (pattern recognition)	Go fosters children's mathematical reasoning by promoting pattern recognition, generalization, and justification. The spatial numerical forms integrated into the Go curriculum—visual patterns that organize numbers for counting—support students’ understanding of multiplication and problem solving. With teacher guidance, students progressed from finger counting to grouping by tens, then to skip counting with arrays, and ultimately to using the board grid for multiplication, demonstrating how spatial engagement deepens mathematical understanding.

The individual studies targeting older adults aged 65 and above consistently involved participants with no prior experience playing Go. Interventions lasted for 12 weeks, 15 weeks, or six months, with each session typically lasting one to two hours. These were delivered either in-person or through non-face-to-face formats. Findings suggest that Go interventions may slow the progression of Alzheimer’s disease and alleviate symptoms through biological mechanisms such as the upregulation of brain-derived neurotrophic factor (BDNF), which is associated with improved dementia rating scores. Participants with dementia or cognitive decline demonstrated improvements in both global cognition and specific domains, including working memory, short-term memory, attention, logical memory, and visuospatial functioning. fMRI data also revealed increased activity in brain regions associated with semantic memory, cognitive control, and reinforcement learning. While improvements in global cognition were noted, the role of intervention duration and Go skill acquisition in sustaining these gains remains an area for further research.

Four individual studies—three qualitative and one quantitative—investigated the effects of Go on the cognitive and mathematical development of children in grades 2–6. Go activities ranged from 8-week programs to yearlong classroom integration, with sessions lasting 1–2 hours. The quantitative study reported that 16 weeks of Go training reduced ADHD symptoms and improved attention, executive function, verbal working memory, and visuoperceptual skills. The qualitative studies emphasized the role of the Go game in fostering mathematical reasoning practices, such as representing, conjecturing, justifying, convincing, and generalizing. This qualitative dissertation research conducted by Yu (2021), in particular, found that spatial thinking played a key role in supporting young children's mathematical reasoning while learning Go. Students used spatial forms—such as grids, shapes, and special number shapes—to externalize

reasoning, observe patterns, justify ideas, and develop score-counting strategies. Over time, students adopted various spatial numerical forms for score-counting, which led them to discover new math concepts like multiplication and develop flexible problem-solving strategies. This visual system—where numbers emerge from patterns of stones and board lines—promotes spatial thinking, enabling children to count and calculate by recognizing, rearranging, and combining shapes both mentally and physically.

Discussion

This review study examined the potential cognitive benefits of playing Go, with a focus on cognitive maintenance in older adults and cognitive development in children. Research in this area is still developing, driven in part by advances in neuroimaging. Most studies have been conducted in Japan, Korea, and China, where Go is widely played and culturally significant. The evidence indicates that Go gameplay may enhance cognitive functioning across age groups. Go interventions and programs can support reasoning, problem-solving, attention, memory, and executive function in children, while helping older adults increase cognitive reserve, ameliorate cognitive decline, and enhance overall quality of life.

Converging Evidence of Cognitive Enhancement

The findings are supported by three converging lines of evidence from existing research. First, studies using biological outcome measures have shown increased serum levels of BDNF (brain-derived neurotrophic factor) following Go interventions—an upregulation that is typically associated with reduced cognitive decline. Second, EEG-based studies demonstrated that following Go intervention, children with ADHD exhibited a significant reduction in the right-hemisphere theta/beta ratio compared to those in a control group. This decrease is generally

interpreted as a positive neurophysiological change, reflecting enhanced prefrontal cortex function associated with improved attention and cognitive control. In older adults aged 65 and above, the acquisition of Go skills and regular gameplay have been shown to induce changes in brain activity, as measured by positron emission tomography (PET). Specifically, increased FDG uptake has been observed in the left middle temporal gyrus (MTG), the bilateral putamen, and the left frontal lobe—regions associated with higher cognitive functions such as semantic memory and lexical retrieval. These findings suggest that Go may serve as a cognitively enriching activity that supports language processing and memory in later life. Third, studies employing pre- and post-intervention cognitive assessments such as the Digital Span Test (DST), Trail (TMA), Trail Making Tests (TMT), Children’s Color Trails Test (CCTT), Mini-Mental State Examination (MMSE), and the Montreal Cognitive Assessment (MoCA) have shown improvements in both global cognitive functioning and specific domains, including attention, memory and executive function.

Overall, these diverse methodologies lend strong support to the view that playing Go can improve symptoms in children with neurodevelopmental conditions such as ADHD and enhance cognitive health in older adults, including those with typical cognitive aging as well as those experiencing impairments related to dementia, Alzheimer’s disease, or age-related decline.

Educational and Cognitive Benefits of Go for Children

As an educator, the author of this review is particularly interested in bridging the Go community and the field of education by highlighting Go’s potential cognitive and learning benefits for children. From this perspective, it is especially important to revisit the two

classroom-based studies included in the review, as they demonstrate how Go can be meaningfully integrated into educational settings.

Through qualitative analysis focusing on students' interactions around the games, McFeetors and Palfy (2018) found that children engaged in strategic reasoning and core mathematical practices—such as representing, explaining, analyzing, conjecturing, justifying, refuting, and generalizing. With teachers facilitating learning through strategic questioning and prompts, students demonstrated not only cognitive growth but also a shift in mathematical disposition, moving beyond deficit-based self-perceptions as they developed a deeper appreciation for logical thinking and reasoning. grew out of a context that required logical thinking.

Yu (2021) conducted an in-depth study on how Go lessons and gameplay support mathematical learning. The study found that spatial forms—a core aspect of Go—promoted pattern recognition and classification, which were essential for deriving general rules and externalizing reasoning. These spatial activities fostered key mathematical practices such as conjecturing, justifying, and generalizing. Students actively engaged in reasoning, often offering spontaneous justifications during teacher-led discussions. Over time, they internalized these practices, applying them independently during cooperative play. The findings suggest that Go not only embeds mathematical concepts but also cultivates transferable reasoning skills through spatial thinking.

In addition, Yu's study found that the Go curriculum examined in her research, which was developed by the Go teacher, effectively supported young children's understanding of arithmetic by guiding them through a progression of increasingly sophisticated spatial-numerical strategies,

particularly through the use of spatial numerical forms such as base-ten number shapes integrated into score-counting activities. These “spatial numerical forms”—specific spatial arrangements—were assigned memorable and child-friendly names to facilitate recall and application. Children used these forms to compute their scores more efficiently. The spatial arrangements included base-ten representations, such as rectangular tens and the “turtle ten,” which were constructed by rearranging Go stones either on the Go board’s matrix layout or beyond its boundaries. Initially, students counted stones one-by-one but gradually adopted more advanced strategies such as grouping by tens, forming arrays, and using board dimensions for multiplication or subtraction. These practices fostered key arithmetic concepts like place value, skip counting, and multiplicative reasoning, and encouraged students to flexibly apply and compare different methods for efficiency. The teacher played an important role in guiding these developments, using visual prompts and encouraging strategy diversification and justification.

Go offered a rich spatial and numerical context that supported young learners in internalizing and applying foundational math concepts. For instance, Yu (2021) observed two students finishing a game on a 7x7 board; when time ran out, one student hadn’t finished counting but was able to calculate his score by subtracting his opponent’s score from the total (49 minus 2 minus 2), demonstrating flexible mathematical reasoning.

The qualitative studies discussed above investigated the teaching and learning of Go within classroom environments, providing valuable insights into the educational potential of the game. They emphasized how intentional collaboration with teachers can support the integration of Go as a purposeful and engaging context for fostering students’ mathematical reasoning, spatial thinking, and other essential cognitive skills. Beyond these, the studies also highlighted how playing Go can cultivate persistence in problem-solving and help develop a positive mindset

toward tackling mathematical challenges. Together, these cognitive and affective benefits can enable students to become more strategic and resilient learners, with transferable thinking skills that support their everyday math learning processes.

Advancing Future Research on Go's Cognitive Benefits

This review provides evidence that playing Go supports cognitive development in children and helps maintain cognitive function in older adults. Its effectiveness as a cognitive tool stems from a unique combination of features: high intellectual demand, strategic depth, and simple, accessible rules. These qualities make Go engaging and adaptable across age groups and cognitive levels. Given its potential for sustained participation and low barriers to entry, Go presents a promising avenue for larger-scale research. It holds potential both as a therapeutic and enrichment tool for cognitive health and as a viable educational strategy for enhancing children's cognitive abilities.

While the findings of this review are promising, several considerations are essential for designing effective Go-based cognitive interventions. Many existing studies involve relatively short intervention periods, often lasting less than four months, and are based on small sample sizes—both of which limit the strength and generalizability of their findings. Future research should prioritize longer-term interventions (exceeding four months) with more diverse and larger participant groups to better assess sustained cognitive outcomes and real-world applicability. Although social interaction is not the sole driver of cognitive improvement, it plays a meaningful role in fostering engagement and reducing isolation—particularly for older adults experiencing cognitive decline.

Most current studies have been conducted in controlled settings or regions with established Go-playing cultures, raising questions about the feasibility of implementing Go-based programs in settings where the game is less familiar, such as in Western educational systems. One promising direction is to introduce Go in early grade levels through classroom-based or after-school programs. To support this, researchers and educators must work collaboratively with the Go community to design instructional approaches that align with learning standards and foster cognitive development. This includes addressing challenges in teaching Go, such as the competitive nature of the game, to ensure that the learning environment is inclusive and supportive for all students, including those with diverse learning needs and neurodiverse conditions.

Framing Go as both an educational game and a cognitive partner can increase its value for students and teachers alike. Rather than focusing on developing advanced players, the emphasis is on cultivating habits of strategic thinking, collaborative engagement, and cognitive resilience—skills that promote deeper learning and transfer across diverse contexts. This approach not only builds a foundation for sustained cognitive benefits in children, nurturing their growth as strategic thinkers, but also holds potential as a cost-effective intervention. Compared to the high costs of medical care and support for individuals with cognitive decline due to dementia, Go presents an accessible and promising tool for cognitive development and maintenance.

Conclusions

Go is an engaging and intellectually stimulating game that fosters lifelong learning and mental agility. Through the synthesis of existing studies, this review illustrates how Go can

promote cognitive functioning and reasoning. Go games are intrinsically motivating, enjoyable, and accessible—easy to learn yet rich in strategic depth—which makes them particularly well-suited for use in schools, community programs, and therapeutic settings across age groups.

The promising evidence and untapped potential of Go invite researchers, educators, and Go players to collaborate in exploring and expanding its role as a versatile resource for both cognitive development and educational innovation. Interdisciplinary collaboration provides a valuable opportunity to explore how this long-standing game can enhance thinking, problem-solving, and lifelong learning in diverse educational and therapeutic contexts.

References

- Arksey H, & O'Malley L. (2005). Scoping studies: Towards a methodological framework. *International Journal of Social Research Methodology*, 8(1), 19–32.
<https://doi.org/10.1080/1364557032000119616>
- Bayeck, R. Y. (2020). Examining board gameplay and learning: A multidisciplinary review of recent research. *Simulation & Gaming*, 51(4), 1-21.
<https://doi.org/10.1177/1046878119901286>
- Booth, A. (2016). Searching for qualitative research for inclusion in systematic reviews: a structured methodological review. *Systematic Review*, 5, 74.
<https://doi.org/10.1186/s13643-016-0249-x>
- Chen, P. J., Hsu, H. F., Chen, K.M., Belcastro F. (2022). Effects of Tabletop Games on Cognition in Older Adults: A Systematic Review and Meta-Analysis. *Games for Health Journal*, 11(4), 225-235. <https://doi.org/10.1089/g4h.2021.0132>
- Donovan T. (2017). *It's all a game: The history of board games from Monopoly to Settlers of Catan*. Thomas Dunne Books.
- Gough, D., Oliver, S., & Thomas, J. (2017). *An introduction to systematic reviews* (2nd Edition). London: SAGE Publications. <https://doi.org/10.53841/bpsptr.2017.23.2.95>
- Kim, S. H., Han, D. H., Lee, Y. S., Kim, B-N., Cheong, J. H., & Han, S. H. (2014). Baduk (the Game of Go) Improved Cognitive Function and Brain Activity in Children with Attention Deficit Hyperactivity Disorder. *Psychiatry Investigation*, 11(2), 143- 151.
<https://doi.org/10.4306/pi.2014.11.2.143>

- Lin, Q., Cao, Y. P., & Gao, J. (2015). The impacts of a GO-game (Chinese chess) intervention on Alzheimer disease in a Northeast Chinese population. *Frontiers in Aging Neuroscience*, 7, Article 163. <https://doi.org/10.3389/fnagi.2015.00163>
- Lizuka, A., Suzuki, H., Ogawa, S., Kobayashi-Cuya, K. E., Kobayashi, M., Takebayashi, T., & Fujiwara, Y. (2018). Pilot randomized controlled trial of the GO game intervention on cognitive function. *American Journal of Alzheimer's Disease & Other Dementias*, 33(3), 192-198. <https://doi.org/10.1177/1533317517753362>
- Lizuka, A., Suzuki, H., Ogawa, S., Kobayashi-Cuya, K. E., Kobayashi, M., Inagaki, H., Sugiyama, M., Awata, S., Takebayashi, T., & Fujiwara, Y. (2019). Does social interaction influence the effect of cognitive intervention program? A randomized controlled trial using Go game. *International Journal of Geriatric Psychiatry*, 34, 324-332. <https://doi.org/10.1002/gps.5024>
- Lizuka, A., Suzuki, H., Ogawa, S., Kobayashi-Cuya, K. E., Kobayashi, M., Takebayashi, T., & Fujiwara, Y. (2019). Can cognitive leisure activity prevent cognitive decline in older adults? A systematic review of intervention studies. *Geriatrics & Gerontology International*, 19(6), 469-482. <https://doi.org/10.1111/ggi.13671>
- Lizuka, A., Ishii, K., Wagatsuma, K., Ishibashi, K., Onishi, A., Tanaka, M., Suzuki, H., Awata, S., & Fujiwara, Y. (2020). Neural substrate of a cognitive intervention program using Go game: a positron emission tomography study. *Aging Clinical and Experimental Research*, 32(11), 2349-2355. doi: <https://doi.org/10.1007/s40520-019-01462-6>

- Lizuka A, Ura C, Yamashita M, Ito K, Yamashiro M, Okamura T. (2024) "GO" to move toward dementia-friendly communities: A pilot study. *Brain Behav.*, 14(6), 3581.
<https://doi.org/10.1002/brb3.3581>
- McFeetors, P. J., & Palfy, K. (2018). Educative experiences in a games context: Supporting emerging reasoning in elementary school mathematics. *The Journal of Mathematical Behavior*, 50, 103-125. <https://doi.org/10.1016/j.jmathb.2018.02.003>
- Nakao, M. (2019). Special series on "effects of board games on health education and promotion" board games as a promising tool for health promotion: a review of recent literature. *BioPsychoSocial Medicine*, 13(5). <https://doi.org/10.1186/s13030-019-0146-3>
- Nightingale, A. (2009). A guide to systematic literature reviews. *Surgery*, 27(9), 381-384.
<https://doi.org/10.1016/j.mpsur.2009.07.005>
- Noda, S., Shirotaki, K., & Nakao, M. (2019). The effectiveness of intervention with board games: a systematic review. *BioPsychoSocial Medicine*, 13,
<https://doi.org/10.1186/s13030-019-0164-1>
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., & Mulrow, C. D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *PLoS Med* 18(3): e1003583. <https://doi.org/10.1371/journal.pmed.1003583>
- Pozzi, F. E., et al. (2023). Can traditional board games prevent or slow down cognitive impairment? A systematic review and meta-analysis. *Journal of Alzheimer's Disease*.
<https://doi.org/10.3233/JAD-230473>

- Raichle, M. E. (2009). A paradigm shift in functional brain imaging. *The Journal of Neuroscience*, 29(41), 12729–12734. <https://doi.org/10.1523/JNEUROSCI.4366-09.2009>
- Tromp, J. (n.d.). *Number of legal Go positions*. <https://tromp.github.io/go/legal.html>.
- Van Horn, J. D. and Toga, A. W. (2014). Human neuroimaging as a "Big Data" science. *Brain Imaging and Behavior*, 8(2), 323-331. <https://doi.org/10.1007/s11682-013-9255-y>
- Yu, Y. (2021). *Spatial Thinking and the Learning of Mathematics in the Game of Go*.
[Unpublished doctoral dissertation]. Northwestern University.
<https://doi.org/10.21985/n2-4h9w-b530>