Robot-Delivered Cognitive Stimulation Games for Older Adults: Usability and Acceptability Evaluation

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Cognitive stimulation games delivered on robots may be able to improve cognitive functioning and delay decline in older adults. However, little is known about older adults' in-depth opinions of robot-delivered games,

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as current research primarily focuses on technical development and one-off use. This article explores the usability, acceptability, and perceptions of community-dwelling older adults towards cognitive games delivered on a robot that incorporated movable interactive blocks. Semi-structured interviews were conducted with participants at the end of a 12-week cognitive stimulation games intervention delivered entirely on robots. Participants were 10 older adults purposively sampled from two retirement villages. A framework analysis approach was used to code data to predefined themes related to technology acceptance (perceived benefits, satisfaction, and preference), and usability (effectiveness, efficiency, and satisfaction). Results indicated that cognitive games delivered on a robot may be a valuable addition to existing cognitive stimulation activities. The robot was considered easy to use and useful in improving cognitive functioning. Future developments should incorporate interactive gaming tools, the use of social anthropomorphic robots, contrasting colour schemes to accommodate macular degeneration, and cultural-specific imagery and language. This will help cater to the preferences and age-related health needs of older adults, to ultimately enhance usability and acceptability.

CCS Concepts: • **Computing methodologies** → **Cognitive robotics**; • **Human-centered computing** → **Human computer interaction (HCI)**; *HCI design and evaluation methods*; *Usability testing*;

Additional Key Words and Phrases: Human-robot interaction, user perspective, cognitive robots, interactive games, gerontechnology, cognitive stimulation, technology acceptance

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1 INTRODUCTION

Neurocognitive changes, especially decline, have been widely accepted as a normal part of ageing [1, 2]. Crystallised intelligence, such as vocabulary, may remain stable or even improve with age, while fluid intelligence, processing speed, psychomotor ability, memory, and conceptual reasoning often decline gradually [3]. Changes in the brain are thought to explain this cognitive decline. Specifically, possible explanations include reduced volume of grey matter [4] and neuronal loss due to the death of neurons [5] and changes in the size and number of connections [4, 6].

Importantly, cognitive decline is considered normal only when it does not interfere with daily functioning and activities [1, 7]. Cognitive decline is considered abnormal when it is reported by the patient or a collateral source (e.g., spouse, child) and when performance on objective testing is significantly lower than would be expected for someone's age and educational/occupational attainment. Rapid decline in cognition and the onset of cognitive impairments (e.g., dementia) can make it increasingly difficult for older adults to live independently and participate in society, increasing dependence on health, welfare, and social support systems. However, non-pharmacological cognitive stimulation activities have been found to protect against age-related cognitive decline [8] by supporting resilience and potentially increasing cognitive reserve [9].

Cognitive stimulation broadly refers to any activity that intends to improve cognitive functioning [10], although the benefits of these activities are often critiqued to be non-transferable to everyday function or untrained tasks [11, 12]. Traditionally, these activities may include reading, word games (e.g., word find and crosswords), puzzles, card games, chess, mah jong, strategy games, and physical activity, especially using the hands. As with most healthy behaviours, these activities can be used as a preventative measure and should be engaged in frequently. In fact, research shows that cognitive stimulation activities should be started early, as age-related decline may begin after midlife, and accelerates after 60 or 70 years of age in healthy individuals [13, 14].

Although traditional stimulation activities are widely accepted, they vary greatly in terms of conclusive and measurable benefits, level of supervision required and the difficulty and frequency of sessions [10]. This may be because, unlike gamified interventions specifically developed to improve cognition, existing games such as bingo and crosswords were developed for entertainment but do require cognitive effort. Advances in cognitive stimulation activities can help to overcome these shortfalls.

Gerontechnology is an emerging field in the application of therapeutic technologies aimed at older adults. Cognitive therapies such as games may be delivered on various technologies, including computer systems, tablets, and mobile phones. Games are already a popular leisure activity amongst older adults, as they are enjoyable [15] and promote social interaction [16]. Additionally, many digital cognitive stimulation games have been evaluated with older adults (aged 65+) and been found to improve cognitive skills, maintain self-confidence [17], and increase reaction time [18, 19]. Digital games have also been well accepted by older adults. For example, a tablet-based casual game *CogniPlay* comprising two games (identifying changes in an image and a matching memory cards game) was evaluated with eight older adults [20]. Importantly, all participants were willing to play the game in the future.

More recently, robots have been developed as novel methods of delivering cognitive stimulation activities for older adults, especially those with abnormal cognitive decline, such as mild cognitive impairment (MCI), dementia, and Alzheimer disease. In a recent pilot study, the robot *Tangy* successfully learned and autonomously facilitated bingo game sessions for 18 older adults with normal cognition or MCI at a long-term care facility [21]. Residents reported that they would attend a robot-facilitated bingo session in the future [21]. Another robot, *Hector* from the CompanionAble Project, delivers cognitive games to older adults with MCI through an iPad, along with providing general home-based support and medication reminders [22]. *Pepper*, designed for stimulating older adults with early-stage dementia, can also be controlled via a touch screen [23]. This robot is interactive, allowing users to communicate by voice and tactile sensors on its head, hands, and feet. The games delivered on *Pepper* also feature three different levels of complexity [23]. Other robots aimed at older adults with MCI and Alzheimer disease record user task performance and autonomously adapt the difficulty of games [24] or provide motivation and encouragement [25].

Games robots are a novel contribution to geriatric care. Existing robotics aimed at older adults include companion robots such as harp seal *Paro* [26], who helps to combat loneliness [27] and assist with reducing stress [28] and lowering blood pressure [29]. *Care-O-Bot* [30] is also used in elderly care to provide functional support, such as fetching and carrying objects and reminding users to take medications and guide them to their appointments. However, these companion and service robots do not focus on providing cognitive stimulation.

Evidently, robots pose various advantages over physical and digital games. First, they can store data and tell us about user interaction (e.g., mood, length and frequency of use, and task performance). Second, cognitive stimulation games presented on a robotic interface may be more effective than those not on a robotic interface [31]. In one study, users reported higher motivation to complete the games on a *LEGO* robot compared with when they were delivered on a tablet [31]. Flexibility in their design may enable robots to be more engaging, interactive, and autonomous. Due to this, they may alleviate the need for human facilitation and enable solo gameplay for older adults living alone.

Nevertheless, the evidence base for cognitive robot games is lacking, particularly regarding the perspective of the user and for adults with normal age-related cognitive decline. This was also reported in a recently published review, which concluded that more resources and research should be allocated to home-based cognitively assistive robots for older adults without dementia [32]. Acceptability and usability are crucial factors for adoption and in ensuring that older adults want to

Fig. 1. Photograph showing the cognitive games robot being used by a participant.

use the robots and continue to do so, as ongoing use is vital for improving cognition. However, to date, little is known about older adults' in-depth opinions of robot-delivered games, as current research primarily focuses on technical development, system evaluation, and experimental research determining the effectiveness of robot-delivered games for older adults with and without MCI or dementia [20, 21, 30, 31, 33–35]. Similarly, research on the use of robotics for older adults tends to focus on one-off use [36]. The aim of the present study is to explore the usability, acceptability, and perceptions of community-dwelling older adults in regard to a cognitive games program delivered on a robot. This study builds on previous usability evaluations in which 10 older adults used an earlier version of the robot but had limited use [34, 37].

2 THE ROBOT

A stationary robot was used to deliver the cognitive stimulation games. Developed by Robocare in South Korea, the robot featured 2×1 DOF tilting wings with a pan/tilt touch screen as a head (Figure 1). The robot could interact with users through text-to-speech (TTS) implemented by Google's TTS service. The robot had a base, which sat on a table. Six games were delivered on the robot, three screen-based games (using only the touch screen) and three using additional interactive blocks. Magnets were embedded within the 10 interactive blocks so that they could be attached and detached. Each block also had a touch-screen surface with tactile sensors. The robot delivery of games differed from typical tablet delivery of games in several ways. First, it had an actuator to adjust its face tilt and could adapt its facial expressions [35]. For example, when waiting, it would show blinking eyes and then tilt its gaze up at users to show engagement. Second, the robot referred to itself as an agent by informing users when it was ready to play (e.g., "I am ready"). It also spoke to users. Third, the robot had lights around its base that flashed and, fourth, the robot system included wireless interactive blocks. These behaviours and features may increase the perception of the robot as an agent and improve visuospatial and fine motor skills compared with a tablet alone.

Fig. 2. Screenshot of the Dressing Up game.

The games were developed in Korea to train cognitive functions, including language, memory, calculation, visuospatial function, and executive function. Two neurologists, five clinical neuropsychologists, and one language pathologist reached consensus in determining detailed contents of each robotic program. All games had 10 levels of varying difficulty. Users could select their preferred level at the start of the game. At the end of each level, participants could see their overall score and choose to repeat the level or advance to a higher one. They could end the game at any point and choose a more difficult or easier level. Many of the original games were in Korean and were reflective of the Korean culture. Six games were selected as they were expected to be easily understood by people from western countries and were translated into English. These include Dressing Up, Cooking, Hide and Seek, Block Matching, Find It Quickly, and Memory. Kim et al. [33] previously tested the effectiveness of an earlier version of the games with older adults in South Korea and found that they reduced age-related thinning of the cerebral cortex. Additionally, performance on traditional paper and pen cognitive evaluations was significantly better in those who played the games compared with those who did not. In a recent evaluation with 46 older adults with MCI in South Korea, the games were found to significantly improve working memory in participants who played the games over a 4-week period compared with those who did not [35].

The aim of the Dressing Up screen-based game was to improve visuospatial skills and working memory, whereby the user had to memorise the clothes that a character wore (Figure 2). The robot would verbally describe the clothes (the type of garment, colour, and specific pattern) and the user would be required to memorise the clothes and drag them to the character. As the levels progressed, more clothing and accessories with different colours and patterns were introduced.

The Cooking game aimed to improve memory skills. Users needed to memorise the variety of ingredients from the robot's instruction in the screen-based Cooking game (Figure 3). The robot would initially show the ingredients in the fridge, which the user had to memorise. Then, the robot showed a larger list of ingredients from which the user would pick the correct ingredients from memory. They then had to remember the cooking instructions (recipe) to prepare the meal.

In Hide and Seek, the user had to remember where the grandchild character was hiding and the order of the places in which the grandchild hid (Figure 4). This game required working memory and visuospatial skills. Sometimes, a distraction appeared on the screen (e.g., buzzing bee moving around) or a 'blackout' to test delayed memory. Small details on the screen would then change; users needed to identify the changes.

The aim of the memory-based Shape Matching game was to build the pattern as shown on the robot's screen, using the interactive blocks (Figure 5). Each block would show only subsections of the pattern shown on the screen, which the user put together to create the complete pattern. Higher levels required the user to complete more complex patterns.

Fig. 3. Screenshot of the Cooking game.

Fig. 4. Screenshot of the Hide and Seek game.

Fig. 5. Photograph showing the interactive blocks and the Shape Matching game.

The Find It Quickly game focussed on improving attention. In Find It Quickly, the robot showed an image on its screen. The user then had to locate the same object on the blocks by tapping the block's touch screen within the time limit. Higher levels would include more objects to locate, more objects to choose from, and finding multiple objects in a specific order. In this game, reaction time, speed, and accuracy were important.

The aim of the Memory game was to improve memory by locating the pattern as shown on the screen using the interactive blocks. First, the user would be required to memorise the object shown on the screen. Then, after a 10-second delay, the user is instructed to find the memorised object from various objects shown on each of the blocks. Higher levels of difficulty required the user to remember multiple objects.

3 METHODS

The study has a qualitative, deductive design. Ethics approval was granted from the University of Auckland Human Participants Ethics Committee in October 2019 (reference number 023830). A multidisciplinary team of health researchers, computer scientists, and engineers conducted this research. The researchers involved in collecting and analysing the data did not have existing relationships with the participants. They had also not been involved in the development and design of the robot, which was important to help minimise bias. The interviews were conducted from February to June 2020.

3.1 Setting and Sampling

This study was undertaken within the follow-up phase of a randomised controlled trial (RCT) conducted between New Zealand and South Korea. In this RCT, 40 participants were recruited across both countries, with half randomised to the control group (daily routine) and half to using the cognitive games robot for up to 24 sessions over a 12-week period. Since recent meta-analysis has shown that there is little evidence to support a dose-response relationship between the amount of cognitive training and the outcome [38], we planned a more practical schedule of 24 sessions rather than 60 sessions. In addition, previous research has shown that 24 sessions of cognitive training can be effective for healthy older adults [39]. This number of sessions was expected to give participants a solid understanding of the robot and its functions. The interviews in this study were conducted with 10 participants who had been randomised to the robot games group in New Zealand. This meant that all participants had experience with using the cognitive games robot and did not incur significant additional commitments.

Participants were recruited from two retirement villages in Auckland, New Zealand. Participants provided written and verbal consent. The eligibility criteria were being older than 60 years, speaking English, and having normal cognition as determined by a score of 25 to 30 on the Mini-Mental-State-Exam (MMSE) [40]. Participants were excluded if they did not meet these criteria or if they had a history of neurological or psychiatric disorders or were taking any medications or receiving medical treatment that may affect cognition (i.e., antihistamines, antidepressants, or chemotherapy).

Participants in the robot games group were taught how to use the robot and were offered ongoing technical support over the 12-week period. They attended two sessions weekly during this time (maximum 24), which were each up to 1 hour long. Game play was self-directed so that participants could choose which games they wanted to play and at what level. A logbook, pen, and clock with a calendar function were provided for participants to sign in and sign out of their sessions. Mood and cognition were assessed at the beginning of the intervention period and at the end to examine any changes. During the follow-up session, participants were invited to be interviewed. All agreed to participate. The data from the interviews are presented in this article.

3.2 Interview Procedure

A researcher experienced in qualitative research methods conducted one-on-one semi-structured interviews in person and over the phone. In-person interviews were conducted in a quiet and private room at both retirement villages. The interviews explored acceptability and usability of the robot games through questions on perceived benefits, preference compared to other activities, satisfaction, effectiveness, and efficiency (learnability, memorability time, and effort; see Box 1). Interviews were audio-recorded. The entire procedure took approximately 30 minutes, including set-up and providing the opportunity to answer any questions. Interviews were transcribed verbatim upon completion. Saturation was reached after the eighth interview.

Box 1. Interview Schedule

- Do you think the cognitive games on the robot could have some benefits? *What do you think some benefits might be?*
- Over the last 12 weeks, have you done any cognitive activities not on the robot (for example, sudoku or puzzles)?
- Did you prefer the robot games or the other activities you did? *Why?*
- Overall, were you satisfied with the robot games? *Why/why not?*
- Did they meet your expectations? *Why/why not?*
- Do you think the games were effective in improving your cognition? *Why/why not?*
- How do you think the robot games could be improved?
- How easy was the robot for you to use? *What made it easy to use (or not)?*
- How much effort did it take to learn how to use the games?
- How hard was it to remember how to use the games each time?
- Did anything else influence your attitude toward the robot and games in general? For example, what other people said or previous experience? Can you tell us about what influenced you?

Note: The questions in italics were prompts.

3.3 Data Analysis

Two researchers used a deductive framework analysis approach to analyse the data by matching it to predefined themes [41]. One researcher had a public health background and the other health psychology. A coding framework of the themes was created on Microsoft Excel, into which data were recorded. Coded data were then summarized under each theme.

The coding framework was guided by previous literature that contained existing theories and themes on the usability and acceptability of technology. The coding themes for acceptability were determined by Ayala and Elder's [42] definition of acceptability. Acceptability is defined as the extent to which an intervention or product is received by and meets the needs of a target population. Themes include (1) preference, (2) perceived benefits, and (3) satisfaction. Usability dimensions for coding were informed by the International Organisation for Standardisation [43]. The key characteristics of system usability include (1) effectiveness, (2) efficiency, and (3) satisfaction. As the theme of satisfaction overlapped between acceptability and usability, it was combined and reported under acceptability.

4 RESULTS

4.1 Participant Summary

Ten older adults were interviewed. Participants were aged between 64 and 86 years ($M = 78.2$, $SD = 6.96$) with MMSE scores ranging between 25 and 29 (see Table 1). Eight participants identified as

Table 1. Summary of Participants' Demographics and Games Sessions Completed

Participant code	Gender	Ethnicity	Age (years)	Highest qualification	MMSE score	Games sessions completed (of 24)
1	Male	NZ* European	81	Technical certificate	29	23
2	Female	NZ European	83	Bachelor's degree	25	23
3	Female	NZ European	85	Technical certificate	30	22
4	Female	NZ European	70	Bachelor's degree	29	1
5	Male	NZ European	86	Technical certificate	26	1
6	Male	NZ European	81	High school graduate	28	24
7	Female	English	74	High school graduate	29	23
8	Male	NZ European	78	Technical certificate	29	24
9	Male	English	80	High school graduate	26	6
10	Female	NZ European	64	High school graduate	30	3

Note: *NZ = New Zealand.

New Zealand European and two as English. Two participants reported having a bachelor's degree as their highest qualification; four had a technical certificate and four had graduated from high school.

The total number of robot games sessions completed varied between participants, from one to 24 ($M = 15$, $SD = 10.65$). Each of these sessions was up to 1 hour long and was self-directed. The two participants who had completed only one session each cited reasons such as that the games were too much of a time commitment and competing priorities. The two participants who had completed six and three sessions, respectively, decided to stop due to the COVID-19 pandemic (caused by severe acute respiratory syndrome coronavirus 2) and lockdown restrictions. In New Zealand, retirement villages were completely restricted to visitors and residents were required to practice social distancing during the pandemic. Although residents could access the room in which the robot was located, some felt uncomfortable with this and decided to minimise any contact with others.

The interaction between the themes and subthemes relating to acceptability and usability are shown in Figure 6.

4.2 Acceptability

4.2.1 Preference (Relative to Other Activities). Participants accepted the robot games as a cognitive games training program rather than as a casual game or entertaining activity. The games were not considered 'addictive' (P10) and, when compared to their preferred activities, individuals reported them being a weekly commitment.

I found it was a commitment; I was conscious that it was a commitment. (P06)

Fig. 6. Diagram showing the themes and related subthemes.

This was reflected in half of the participants preferring other casual activities (crosswords, code-cracker, reading, puzzles, and online card games). This was because the robot games were seen as more testing and challenging, especially as they had a time pressure. As a result, some participants felt that they could not win on the robot. One participant reflected on why he subconsciously avoids challenging tasks: *As you get older you like to do things that don't test you as much, as you were tested in your life and normal times anyway.* (P08)

However, two participants enjoyed the challenge and preferred the robot games to their usual activities. Three participants did not have a preference and enjoyed the robot games, as they were different from their usual activities. They were seen as another cognitive tool that could be used to complement existing activities.

They're testing different things. They're relying on different patterns of thought... It's good to do some other things that are going to make you think. It's like switching in between knitting and crochet. You're applying two different techniques and you've got to remember what those techniques are and that's better than having one that's always the same. (P04)

I can't say I preferred one over the other... If I had them at home, then that'd be one more in the armoury. (P10)

4.2.2 Perceived Benefits. All participants expected that cognitive stimulation games delivered on a robot would be beneficial in improving cognitive functioning and related skills in general. Improvements in the following areas were predicted: memory, focus, alertness, concentration, problem solving, logical thinking, attention to detail, reaction time, and patience. These benefits were expected to transfer to most users.

I would imagine that if you do them for long enough, that it would improve your memory. (P07)

Participants also reported a potential benefit regarding users learning about their memory. Specifically, succeeding at the games would enhance one's confidence in one's memory. Alternatively, the games could also alert the user about one's memory loss or possible cognitive decline.

I suppose the benefits are if you're doing okay at them, then that would give you more confidence about your memory and your ability to react to information quickly. (P04)

It gives people an insight into memory loss as they get older. (P08)

4.2.3 Satisfaction. All participants reported being satisfied with the games. They were also mostly understanding of technical problems that sometimes occurred with the interactive blocks not responding or lagging.

I thought the games themselves were quite good and I think we've discussed the occasional teething problems you've had with the equipment. And that's annoying, but that's to be expected with new programs and equipment. (P01)

In general, participants reported not knowing what to expect, as they had no previous experience in using robots and some had limited experience in using computers and playing games on them. They therefore agreed that they were satisfied, as the robot games had met their expectations.

I didn't really have any expectations. Because until you start doing it, you don't really know what it's going to be. (P07)

Well, I suppose I didn't really have any expectations of what they were going to be like. So, yes. It was something different and playing games and things, which I've never really done on a computer at all. (P04)

4.3 Usability

4.3.1 Effectiveness. Six participants thought that the robot had been effective in improving their own cognition, as reflected in observed improvements. They noticed changes in their thinking when doing their other activities, such as when playing card games that require problem solving. They also thought that their progress in moving up levels in the robot games demonstrated cognitive improvements.

Yes—I do. Well, it made me be aware. I had to observe things, not just be fuzzy about things or be unaware of things. You had to concentrate. If it [cognition] has changed, it would be marginally for the better. (P06)

I think there has been a slight improvement... Well, I think I'm actually getting better at trying to work things out and think, perhaps taking time to think it through, rather than to say "I don't know what this is" and just leaving it... I play quite a tricky card game at home and there are moves that you're not allowed to make... Sometimes you have to go right back to the beginning again and find a different way, and I'm finding I was doing that much more confidently. (P03)

Well, I improved on the levels, so it [cognition] must've improved. (P09)

One participant also reported feeling energised and more alert immediately after playing the games, rather than tired.

Because they make you a little more alert, so you become clearer of mind, clearer of thinking. Less tired and more alert basically. I would say that there was a feeling after the game. I didn't come away tired. I came away a little bit energised. (P10)

The other four participants acknowledged that the games could be effective in improving cognition, as any challenging activities are good for the brain. However, they thought that more use and long-term observation was needed to conclude whether the games were effective in improving their own cognition. Two of the participants had completed only one session.

Cognition is always improving slightly if you're practising games. (P02)

4.3.1.1 Improvements. Participants suggested various improvements to the robot to make the games more effective and the robot more usable.

Culture and language: Participants observed that the robot reflected a culture that was unfamiliar to them. It used language and words that they were not familiar with, especially in the Cooking game, in which it asked them to make meals using ingredients such as perilla leaves, bamboo root, and squid.

I think the Americanisms in the cooking thing, I'd never heard of half of the things. There was the perrrririirrla leaf or something rather another, the balloon root—I've never heard of that. Oh, I forget, there were some of the fish things. (P03)

I had a funny feeling where there was one or two [games] where the instructions didn't seem to be in a format that we New Zealanders would perhaps usually use, in terms of terminology. (P04)

The robot also had an American accent; thus, it pronounced words and phrases differently from how they would be pronounced in New Zealand. Participants reported preferring to have their own accent reflected in the robot. The British participants requested an English accent and the others a New Zealand accent.

If it was more New Zealand English spoken it would be easier for me I think. (P06)

Some of them I was quite amused. There was one where she tries to use a different accent. 'Let's go' and she had a pseudo-American accent and I thought 'oh really.' (P07)

Difficulty and colour scheme of Hide and Seek: There was consensus that the Hide and Seek game was the most challenging game and was even considered frustrating. The Cooking and Shape Matching games were preferred, as they were easier. Due to the difficulty in playing the Hide and Seek game, many participants avoided it.

The robot games, I found one of them particularly frustrating because I couldn't master it. ... That used to annoy me; to the point that I didn't get enough reward off it, to the point that I decided that if I didn't need to play it I wouldn't. It was frustrating rather than challenging. (P10)

The colours on one specific image in the Hide and Seek game were also considered to need improving. Participants were drawn to colourful images and did not like the brown colour scheme used in the courtyard image (see Fig. 4). According to participants, this colour scheme and living with age-related macular degeneration made playing the game more difficult.

Well, you've got to get rid of the courtyard! It's all brown—it's horrible! For someone my age and I have got AMD [age-related macular degeneration], so all brown, it was just so difficult to see, especially when they said find the changes. (P03)

It was, boringly similar, too similar. Maybe because it don't have enough colour in it. The colours really bugged me up. They were the browns, they were the boring browns. I just couldn't get into it. (P10)

Blocks: Although participants strongly preferred the interactive blocks over the screen-based games, they were sometimes not reliable. This was highlighted as a potential room for improvement.

I think they're great, but they've got to be improved. I don't know how you would do that... But I got really frustrated with that. (P03)

4.3.2 Efficiency.

Efficiency was evaluated in regard to whether the robot was easy to use, easy to learn to use, and easy to remember to use. All participants reported that the robot was easy to use. However, it was more difficult to use when it required troubleshooting.

It wasn't hard to operate the robot. It wasn't hard at all... Everything was quite clear. (P06)

It wasn't difficult, except when you're trying to fix something, where you switch it off and switch it on. Sometimes the logic in what you're doing is difficult to pick up. (P01)

All participants also found the robot easy to learn to use. This was due to it being self-explanatory and having clear instructions.

I think it was really self-explanatory. I didn't find that I had any problems with that (P07).

Nine participants found it easy to remember to use. One participant stated she could not comment on this, as she only attended one session. Participants reported finding the games easier to use after attending one, two, or three sessions.

I picked up pretty well what was explained to me and I had no problems with the games. (P05)

5 DISCUSSION

Results indicated that cognitive games delivered on a robot may be a valuable addition to existing cognitive stimulation activities. Participants overall were satisfied with the games and had their expectations met. The robot games were accepted as being beneficial to improving cognitive abilities such as memory, problem solving, and reaction time. These same skills tend to decline over age [3]. Regarding usability, the robot was also considered to be usable and effective for improving cognition, easy to use, and easy to remember and learn to use. Suggestions to enhance usability included culture and language that reflect the users and a more colourful scheme in one of the games. Moreover, the interactive blocks could be more robust. These findings suggest that most games and functionalities were well received by the participants and could be considered by developers of cognitive stimulation games. Almost all of the participants were able to reliably interact with the robot over a 12-week period by themselves, even though some had limited experience in using devices such as computers. None had previous experience in using robots.

This study advances understanding in how adults with normal age-related cognitive decline interacted with a cognitive games robot over a period of time. The collection of qualitative data after long-term use was novel, as it enabled broader understanding of the experience of using the robot. Previous and ongoing research on cognitive games robots, including with *Pepper* and *Hector*, focussed on participant samples with MCI, early-stage dementia, and Alzheimer disease [22–24]. However, research shows that cognitive stimulation activities should be started early, as age-related decline may begin after midlife and accelerates after 60 or 70 years of age in healthy individuals [13, 14]. It is therefore important that further research continues to include older adults with normal cognition and normal age-related cognitive decline. Similarly, long-term evaluation of usability is important, as this helps to generate lived experience with the robot rather than relying on participants to imagine using it [36].

Although six specific games were used, implications regarding the design of the robot and games are general and are important considerations for future development of usable and acceptable robotic systems for older adults. As with any technology, robot games must be easy to use, easy to remember to use, and easy to learn to use [44–46]. This is particularly important for older adults, who often have lower self-efficacy and comfort with using digital technologies [47, 48]. Older adults are therefore more likely to accept technologies that have a simple interface and are easy to understand and learn to use [49].

Ease of use and usability are interrelated and crucial to optimising user experience. They are commonly reflected across literature on technology acceptance and use, such as in the Technology Acceptance Model (TAM), which postulates that the perceived usefulness of a technology and its ease of use influences both the intention to use it and actual use [46]. The TAM has been adapted by Bröhl et al. [44] to focus on robotic technology. Accordingly, acceptance of robots and meeting human expectations may predict usefulness, which may lead to acceptance and ultimately result in successful human-robot interaction [44]. In our study, participants were accepting of the robot even though they had no previous experience in using robots. They also stated that the games met their expectations and were easy to learn to use because of a simple interface. However, our research has uncovered a factor that is often not included in technology acceptance frameworks—*aesthetic and visual appearance*.

In our study, aesthetic and visual appearance impacted usability; however, this was due to age-related health needs. The colour scheme was important for participants as many of the older adults had difficulty distinguishing changes in the brown, beige, and grey tones. These were all perceived to be very similar. Some participants could not explain why they had difficulty with the game, but many cited challenges with their vision and, specifically, living with age-related macular degeneration. Age-related macular degeneration, as with age-related cognitive decline, is common with increasing age [50, 51]. In fact, it is the leading cause of blindness in the United States and an estimated 288 million globally will live with macular degeneration by 2040 due to ageing populations [51]. As reflected in our study, this can be characterised by changes in chromatic sensitivity, which worsens with severity [52]. Technology acceptance frameworks—and, consequently, the future design of robot and digital games—should acknowledge that older adults may experience other age-related health problems, such as deteriorated vision. This may create problems in using the robot (in our case, playing the games) and in the appeal of the imagery and overall acceptance of the technology. Colour schemes should include varying and contrasting colours, thick outlines, large shapes, and customisable brightness, which can be easier to see.

Previous developments in robot-delivered games show that they can feature more interactive and engaging functionalities than other digital games by embedding tactile sensors into the robot [23]. This was also reflected in our robot; participants preferred the block games to the simple screen-based games. Incorporating additional mobile game accessories such as blocks may also

encourage hand mobility. This is useful for cognition, as hand movements are a fine motor skill activity that activates the primary motor cortex, cingulate cortex, and the anterior cingulate cortex in the brain [53]. Playing games that require movement of objects also encourages cognitive skills related to psychomotor abilities and hand-eye coordination.

Additionally, the robot's behaviours (e.g., orienting gaze to users, eyes, lights, and speech) may have been beneficial in engaging participants, as they provided a social element. While not the focus of this study, many participants were observed to interact with the robot as a social entity. They often greeted it at the start of the session, sat upright when the robot said it was ready to play the games, said goodbye at the end of the sessions and danced along to the celebratory music when achieving good scores on the games. Future games robots should leverage the ability to socially interact with users (e.g., via speech, gaze, and responsiveness), as this may add to engagement. The flexible design possibilities of robotic systems (such as interactive tools and mobility), appeal to users and may provide unique cognitive benefits (i.e., visuospatial and fine motor skills) compared with traditional digital games. Additionally, future cognitive stimulation games could be delivered on more anthropomorphic robots to establish a stronger social connection between the user and the robot. A recent study presented the same six games on a larger and more mobile robot with more anthropomorphic features (a head and body shape, and arms) and found that users attributed more humanlike characteristics to it and likened it to a companion [54]. Presenting the games on differing robots may impact engagement and, ultimately, use.

Other important design implications for improving acceptability and usability included culturalisation—the localisation and personalisation of culture [55]. In our study, participants wanted to hear the robot speak in their accents. They also reported not being familiar with some of the imagery in the games due to cultural differences. Literature on the development of future games robots supports the need for adapting the language and pronunciation so that it is synonymous to the culture of the user [37]. This requires software developers to understand differences in cultures and translate and adapt language, specific accents, and the imagery used [56, 57]. Ultimately, there is no one perfect design for a robot; instead, robots should offer customisable characteristics [36, 58]. This should include cultural imagery, language, and accent, as well as the brightness of the screen, as discussed earlier in this article.

To our knowledge, this is the first study to explore acceptability and usability through the long-term use of a cognitive games robot by older adults. Despite the participants being healthy, our study uncovered normal age-related health factors that influence technology usability by older adults. This highlights the need for software developers to consider the various health issues that may be experienced through ageing, including macular degeneration, impaired hearing, and cognitive decline. These should be accommodated by enabling personalisations in language and using contrasting colours. Likewise, this study has uncovered a strong preference for interactive gaming tools over traditional screen-based games. This finding and the flexible nature of robots should be leveraged in the future development of innovative games delivered on a robotic interface.

5.1 Strengths and limitations

As with most research on human-robot interaction, self-selection bias may have been present, as participants volunteered to test the robot. Therefore, the sample may have included a group of older adults who are more accepting of technology and robots in general. Many were also willing to continue to use the robots during the COVID-19 pandemic while practicing social distancing. Although a small sample size was obtained, the data provided were rich and detailed, especially as our participants had long-term experience in using the robot, having attended an average of 15 sessions over 12 weeks. However, attendance varied greatly between participants; it is possible that this may have influenced the interview data. Other research exploring human-robot interaction

included similar sample sizes, ranging from one to 26 participants, some with no actual use or only one-off use of the robot technology [21, 23, 30, 36, 37, 59]. In one usability study, a sample size of five was able to identify major issues [30]. In this study, useful recommendations can be made for general design and development to improve the usability and acceptability of other cognitive games robots for older adults.

6 CONCLUSION

This study advances understandings of the user perspective of cognitive games robots by older adults with normal age-related cognitive decline. Co-design of robot-delivered games with, and feedback from, older users is an important step in designing and creating cognitive stimulation games for such users. Positive reactions toward the robot indicated that cognitive games delivered on a robot are a valuable addition to existing cognitive stimulation activities. Older adults perceived the robot to be acceptable and beneficial as a cognitive games program. They also determined that it was easy to use, and some believed it was useful in improving their cognition. Developers may improve the effectiveness of robot games by leveraging their potential for flexible designs. This should focus on incorporating the use of interactive gaming tools (e.g., blocks), enabling adjustments in the screen's brightness, using contrasting colour schemes, and featuring culturalisation in the imagery and language of the robot. This will also ensure that future robot-delivered cognitive games cater to the preferences and age-related health needs of older adults and, consequently, enhance both usability and acceptability.

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