DESIGNING HUMAN–CEILING ROBOT COLLABORATION IN A CORSI BLOCK-TAPPING GAME: ENHANCING COGNITIVE FUNCTION IN THE ELDERLY

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Abstract:

Cognitive deterioration in elderly individuals markedly affects their capacity to execute daily tasks autonomously. Regular cognitive training, particularly when augmented by robotic support, has potential in preserving and enhancing cognitive function. However, several current training methodologies are missing dynamic and engaging components that integrate human-robot collaboration. This study describes a collaborative human-robot cognitive training system that incorporates the Corsi Block-Tapping (CBT) game and a ceiling-mounted robotic arm. As a social assistive robot (SAR) that can be trained to help with memory and visuospatial attention, the device is made to offer elderly people an engaging and entertaining experience beyond what traditional CBT methods can provide. During the preliminary stage, the system exhibited its ability to carry out predetermined sequences through collaborative interaction between the robot and the user. A self-administered test was also conducted to validate the system's basic functionality, confirming its capability to present stimuli, register user responses, and maintain a safe interaction distance through proxemic monitoring. Preliminary findings suggest that this method has the potential to function as a secure, engaging, and proxemically aware medium for cognitive training, despite the fact that formal user evaluations have not yet been conducted. The focus of future research will be on the execution of empirical studies, the enhancement of the user experience, and the refinement of the interaction dynamics between humans and robotics.S

Keywords:

Corsi Block Tapping, Human-Robot Collaboration, Social Assistive Robot, Cognitive Training.

1. Introduction

Aging is a major risk factor for gradual cognitive decline, affecting important aspects such as memory, decision-making, and information processing—all three of which are vital for maintaining the independence of older adults in daily life. As we age, there is a measurable decline in cognitive abilities, especially in tasks that require rapid information processing to make decisions, such as processing speed, working memory, and executive functions. Synapse loss and declines in attention, memory, language, and visuospatial abilities are hallmarks of aging [1, 2].

Although cognitive training as a healthy lifestyle factor effectively maintains and improves cognitive function [1], its implementation in the field faces various challenges. One of the main obstacles is the lack of consistency in following regular training, which is caused by multidimensional factors such as a lack of awareness about the importance of maintaining brain health, limited access to appropriate training methods, and the design of conventional cognitive tasks that are monotonous and cannot maintain motivation in the long term. This gap between scientific evidence and real-world application highlights the need for innovative approaches that are easier to implement and more motivating for elderly users. This approach should combine insights from neuroscience with elderly-friendly design principles. Such integration can enhance engagement in cognitive exercises and lead to improved outcomes. Furthermore, the growing demand for caregivers, which does not match the number available, can lead to caregiver burnout and poor well-being [3,4,5], particularly for those who must accompany older adults in cognitive exercise every day, which is also one of the challenges that must be addressed.

The medical and rehabilitation disciplines have seen a gradual use of robotic technology in recent decades. This includes the cognitive stimulation of the aged [6] and the acceptance of the usage of social assistance robots by the elderly to avoid cognitive decline [7]. Robotic systems offer significant advantages such as multimodal interactions, enhanced feedback, and real-time adaptation based on user performance — all critical factors for boosting engagement and retention in cognitive training [8]. Customizing activities and emulating human-like social interactions using SAR can diminish demotivation [9, 10]. However, numerous studies have demonstrated that numerous contemporary robotic platforms continue to employ a one-way approach when conducting cognitive games or have not evolved into adaptive collaborative partners [11, 12]. To resolve these design obstacles, prior research has recommended the implementation of object-relationship-based egocentric behavior analysis to assist in cognitive rehabilitation. This approach enables a more profound comprehension of the interactions between humans and robots by examining the locations of attention and the manner in which individuals interact with objects. Consequently, robot-based cognitive training is enhanced [13]. One recent work introduced a multiscopic cyber-physical-social system (CPSS) for independent cognitive evaluation through hand–object interaction and visual attention during a block-design test. While effective for individual assessment, it did not address dynamic collaboration [14]. These constraints emphasize the necessity of creating autonomous platforms that facilitate more collaborative and adaptive interactions, particularly for elderly users.

This paper provides an innovative framework that merges cognitive behavioral therapy with a social robotic system to address the issues of collaborative interaction design. CBT has been utilized in neuropsychology for an extended period[15]; however, its conventional application primarily entails passive monitoring, which does not incorporate embodied cognition strategies that may improve training outcomes. The proposed framework combines a social robotic system to develop an active and engaging training setting that actively involves cognitive trainees. This method not only improves engagement but also fosters a more profound comprehension and retention of skills via embodied experiences. Through the use of an RGBD camera for human-robot distance control, our adaptation integrates the proxemic dimension [16] by having the ceiling robot function as a dynamic companion that proactively completes a series of tasks, taking turns with the participant in pressing target blocks. The robot and the participant work together, turning cognitive behavioral therapy (CBT) from a simple test into an interesting training session. This makes it possible to measure cognitive skills in many ways, such as how quickly someone reacts, how well they coordinate their eye and hand movements, and how consistently they work together. Through human-robot collaboration methods, this new design idea creates a new way of thinking about cognitive assessment and intervention that works well together.

This study makes three main contributions that differentiate it from conventional approaches in robot-based cognitive training. First, we develop an innovative prototype for a CBT that changes the paradigm of human-robot interaction from hierarchical instructions to symmetric collaboration, where the robot serves as a partner in conducting cognitive training in the game. Second, this system integrates comfort settings with proxemics during interaction so that comfort and safety in the game are still maintained. Third, to explore this further, the current study investigates the effectiveness of robots as partners in collaborative cognitive training for the elderly.

The structure of this paper is as follows: Section II looks at the latest progress in social robotics for cognitive training and points out areas where the design of human-robot teamwork could be improved. Section III details the initial implementation of the prototype architecture of the developed integrative system design. The paper closes with Section IV regarding the conclusions of the methods proposed in this study.

2. Related Work

This section will provide an overview of relevant research, particularly those on cognitive training for the elderly, the use of robots for social interaction, and the application of CBT in robot-based environments. Paying attention, learning, and using language and memory to respond to objects are all components of cognition. If this cognitive ability is compromised, it will also affect the person's ability to do daily tasks. This reduction in capacity is frequently encountered by the elderly as a result of aging factors; however, cognitive training is carried out with the belief that the brain, even in old age, may still change for the better in order to improve cognitive capacities [17]. The integration of physical and cognitive training has enabled the aged to enhance cognitive functions, diminish memory issues, and sustain emotional health [18].

Engaging physical exercise through games has garnered considerable interest in rehabilitation and cognitive training contexts, as demonstrated by studies that employed a Cable-Driven Parallel Robot (CDPR) combined with Virtual Reality (VR) to enhance the Human-Robot Interaction (HRI) experience [19]. This study demonstrated that CDPR successfully simulated movement within a virtual environment, resulting in a genuine sensation for users that may enhance engagement. One identified challenge was the necessity for additional personnel to facilitate the setup of the equipment before use. A comparable study examined two cognitive training platforms: a social robot and immersive virtual reality (iVR) [20]. The findings indicated that participants favored virtual reality for short-term engagement, whereas both platforms exhibited comparable preferences for long-term training. This study indicates that the integration of social elements, such as robots, with spatial elements, such as virtual reality, may enhance user engagement, particularly among older adults who need cognitive training in a home setting. This study exclusively employed the robot as a companion during the activity.

In another study, close-range safety precautions were implemented to assure user safety, with the robot assisting the user via gestures and spoken interaction modalities [21]. However, there was no direct interaction throughout the game in this study, which would have improved social engagement and companionship while playing. Antonio's previous study presented a symbolic decision-making system aimed at delivering personalized cognitive training for individuals with cognitive impairments, including Alzheimer's disease [22]. The robot modified its behavior in response to the patient's condition, thereby improving patient engagement and performance. While this technique increased patient involvement, it did not address the possibility of game modifications in which the robot would play alongside the user. Other research has also concentrated on using symbolic decision-making systems to offer individualized cognitive training; however, these studies mostly positioned the robot as a social motivator rather than an active participant in the cognitive game [23].

Previous research on human-robot interaction (HRI) frequently neglects the significance of real-time spatial dynamics and active collaboration, instead emphasizing isolated components such as cognitive tasks or movement modeling. In cognitive rehabilitation, robots are frequently regarded as passive companions rather than active participants, which restricts their potential use. Despite developments, present technologies still lack fully collaborative interaction and real-time spatial adaption, which are important components of effective elderly engagement.

We propose a collaborative method involving the robot actively participates in rehabilitation with the user. Our approach modifies task difficulty through real-time feedback and proxemic analysis to enhance spatial interaction. This improves engagement and rehabilitation results by establishing the robot as a genuine training partner.

3. Corsi Block Tapping Game Collaboration Design

The preliminary design of the robot-assisted CBT game is presented in this section. Both the human participant and the robot stand at predefined positions within the personal zone (45–120 cm) [16] at the start of the game to ensure a safe and comfortable interaction distance. According to proxemics theory, this personal zone balances psychological comfort and safety in human-robot interactions, which is especially important for geriatric users who may be sensitive to personal space intrusions. Maintaining this zone reduces user anxiety and promotes effective communication during the game, thereby fostering a comfortable and secure environment that encourages more natural and confident engagement by older adults.

Ten illuminated blocks are arranged on a board to form the game configuration. The blocks light up in a predetermined sequence, which participants must memorize and replicate. The robot initiates the sequence by moving toward the game board and tapping the first illuminated block before returning to its original position. The human player then taps the next block in the sequence. Turns alternate between the robot and the human player until the full sequence is completed. This alternating turn-taking fosters active collaboration, with the robot serving not only as a guide but also as a co-player, enhancing social interaction and engagement. This design addresses limitations of previous studies where the robot's role was mainly motivational rather than participatory.

An RGB-D camera (Intel RealSense D455) monitors the distance between the human participant and the robot. The game automatically pauses if the participant enters the intimate zone, defined as less than 45 cm, to ensure user safety and comfort. This real-time monitoring system dynamically maintains a safe distance by suspending robot actions when the human comes too close. Proxemic awareness is especially important to prevent discomfort or accidental collisions, particularly for elderly users who may have reduced mobility or slower reflexes. This adaptive safety protocol creates a responsive interaction environment that prioritizes user well-being without disrupting gameplay flow.

The game includes two task modes: forward (S1–S5) and backward (S6–S10). In forward mode, players replicate the sequence as presented; in backward mode, they reproduce it in reverse order, increasing difficulty progressively. These modes challenge different cognitive functions such as working memory and executive function, providing comprehensive cognitive training. Performance is assessed using four metrics [24]:

- Corsi Span: The longest sequence that can be accurately recalled.
- Average Corsi Span: The typical span observed in healthy individuals.
- Correct Number of Sequences: The total number of correctly reproduced sequences.
- Immediate Block Forward/Backward Span: The

maximum sequence length at which the user recalls at least two out of three trials correctly.

These metrics are validated in neuropsychological assessments and relevant for evaluating memory and attention improvements during cognitive rehabilitation.

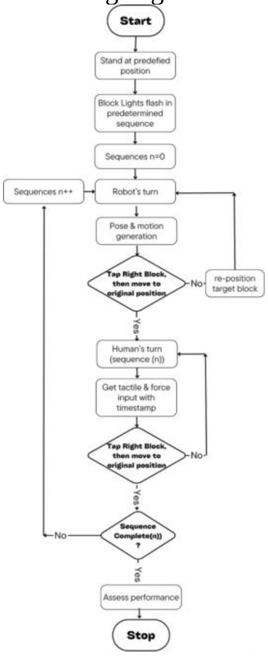

FIGURE 1. System's Flowchart

The system flowchart is shown in Figure 1, while the CBT game prototype is illustrated in Figure 2, which includes visual feedback through color-changing lighting and tactile feedback through FSR UX402 force sensors. The main PC, which regulates robot actions, communicates with a microcontroller unit (Arduino UNO) that processes real-time input from human participants. The system initiates the robot's next action immediately after detecting the human player's tactile input. This bidirectional feedback mechanism enables synchronous human-robot collaboration, ensuring the robot acts only after confirming user responses, thereby creating a seamless and engaging interaction.

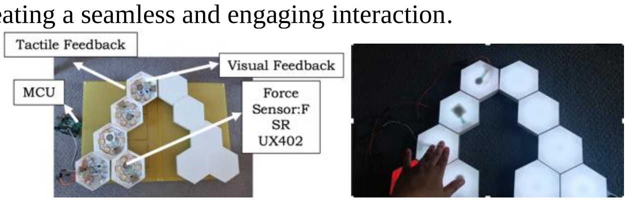

FIGURE 2. CBT Board Game Prototype

The layout of the game is depicted in Figure 3, which is intended for integration into the autonomous living simulation in the Trailer Living Lab. The ceiling-mounted robots used are Kinova Gen3 Lite models, each with 6 degrees of freedom, capable of forward, backward, and rotational movements. This ceiling-mounted design allows flexible and safe robot movement around the user while minimizing obstructions in the living environment, which is especially beneficial for elderly users with mobility challenges.

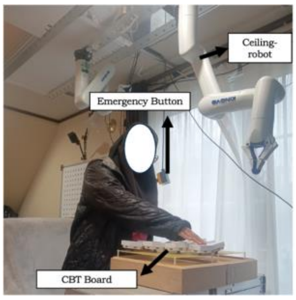

FIGURE 3. Layout of the CBT System

During the game, the robot uses only one arm, with the other arm disabled to maintain a safe position above the player's head. An emergency button is also installed as a crucial safety feature, enabling the player to immediately halt all robot movements if needed. This multi-layered safety design demonstrates a strong commitment to user well-being by providing a quick manual override to mitigate risks during interaction.

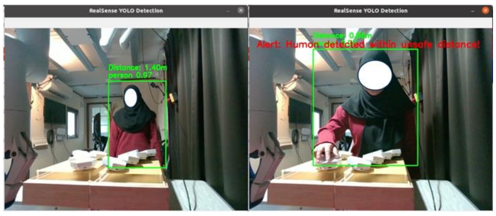
FIGURE 4. Distance Object Detection

Detailed representations of the proxemic detecting system can be found in Figure 4. In order to recognize objects, this system makes use of YOLO, and it also employs an RGB-D camera in order to monitor and react to the distance that separates the robot from the individual. At the beginning of the game, the player's position is shown to be at a safe distance from the robot in the image on the left. On the other hand, the image on the right depicts a distance that is considered to be fairly dangerous, measuring fewer than 120 cm from the robot. This causes the robot to remain still until it detects the human at a safe distance, at which point it will begin to work again. To guarantee that the robot functions efficiently without endangering the user, this safety protocol is implemented. The robot is able to adjust its motions and actions by continuously evaluating the distance between itself and the player, which results in a gaming experience that is both safer and more participatory. This safety protocol ensures the robot operates efficiently while preventing user endangerment, ultimately supporting a collaborative and participatory gaming experience.

3.1. Preliminary Self-Evaluation

To evaluate the operational feasibility of the system, the authors performed self-assessments utilizing the CBT framework designed for human-robot interaction. The test involved completing both forward and backward span tasks, each across five increasing levels of difficulty. The following results were recorded:

- **Forward Span Levels**: 5 (All successfully completed)
- **Backward Span Levels**: 5 (All successfully completed)
- **Total Sequences Attempted**: 10
- **Correct Sequences Recalled**: 10 out of 10

The results demonstrate that the system can reliably present sequences, identify user responses, and validate them in real time for both forward and backward modes. Although these findings derive from self-assessment and do not aim to assess cognitive capacity, they affirm that the fundamental functioning of the system is operational and ready for formal usability testing with actual users. Additionally, the self-evaluation did not reveal any safety or discomfort concerns, suggesting that the contact is suitable and stable for users.

4. Conclusion

In this work, a robot-assisted cognitive behavioral training (CBT) game is designed and implemented with the goal of improving spatial memory and encouraging user participation in cognitive training, especially for older persons. The incorporation of robotics into cognitive behavioral therapy tasks presents a new method for enhancing the interactivity, adaptability, and accessibility of memory training. The game utilizes proxemic monitoring within a cooperative human-robot interaction framework to enhance user safety. The system can adaptively respond to the user's position and performance, facilitating a more immersive and personalized training experience while ensuring a safe interaction distance. The game incorporates tactile and visual feedback mechanisms to enhance interaction and sustain user engagement. Multimodal cues enhance the intuitiveness and motivation of the training environment, which is crucial for ongoing engagement in cognitive tasks. The real-time distance detection system guarantees that the robot upholds an appropriate and comfortable interaction range. This adjustment mechanism improves safety, especially for elderly users, while also fostering trust and comfort in gameplay. Initial findings indicate that the integration of robotic interaction with adaptive training protocols may serve as an effective tool for cognitive rehabilitation. Future research will concentrate on enhancing interaction dynamics between users and robots, optimizing task adaptability in accordance with real-time performance, and implementing longitudinal studies with varied user populations in authentic rehabilitation environments to evaluate long-term effects and usability.

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