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Socially Assistive Robots and Sensory Feedback for Engaging Older Adults in Cognitive Activities

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Motivating older adults to engage in cognitive activities has the potential to slow cognitive decline. This article presents a participatory design (PD) workshop and follow-up prototype evaluation to determine how cognitive training activities can be adapted to integrate socially assistive robots and sensory feedback (visual, auditory, and haptic, specifically). The workshop with older adults and therapists resulted in concrete designs and strategies for engagement. The second phase of this work was to implement these outcomes into a prototype that incorporated a humanoid robot and sensory feedback, with a particular focus on haptic feedback. The evaluation with eight older adults supported the potential of hand tracking with sensory feedback as an interaction mechanism to foster engagement, where the increased workload notably led to high levels of engagement. The prototype results confirmed the strategies and designs from the PD workshop were effective as a way of engaging older adults in cognitive activities. This article highlights the potential for the unique combination of socially assistive robots and sensory feedback to promote older adults' engagement in cognitive activities.

CCS Concepts: • **Human-centered computing** → **Haptic devices**; *Touch screens*; *Auditory feedback*; **User studies**; **Participatory design**; **User centered design**;

Additional Key Words and Phrases: Older adults, Cognitive activities, Participatory Design, Socially assistive robots, Sensory feedback, Multimodal

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1 Introduction

Older adults who engage regularly in cognitive activities, even leisure-based tasks such as Sudoku, have been shown to have higher levels of cognitive performance [17]. Therefore, the aging demographic would greatly benefit from tools that can assist in enhancing engagement with cognitive

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activities. While the formalized technique of **cognitive training (CT)** has been shown to be effective for those with varying degrees of cognitive decline [4, 9, 41], even those with a dementia diagnosis struggle to access this treatment due to factors including logistical considerations, denial of their condition, and motivational difficulties [7, 9]. Furthermore, CT requires appropriate levels of engagement over an extended period of time [9]. When CT is provided, many factors can impede access and adherence to treatment including logistical considerations, denial, depression, and difficulty motivating [7, 9]. Technological resources could assist in meeting this goal while also providing easier access. In the space of rehabilitation, incorporating physically embodied **socially assistive robots (SARs)** have been shown to improve both engagement and performance [64]. Moreover, they can provide social interactions to help encourage engagement [34]. Leveraging different modalities of sensory feedback also has the potential to both improve engagement and performance with CT by providing unique and adaptable means to convey information to the user. For instance, one study found using a beep to deliver information on position error during rehabilitation enhanced patients' performance and engagement as opposed to the typical practice of delivering all exercise information through same sensory channel [51]. In the context of this work, we focus on visual, auditory, and haptic feedback whether that be delivered by an SAR or an external device. This work aims to foster long-term engagement with cognitive activities (this encompasses leisure activities and formalized CT activities) for typically aging older adults (those without **mild cognitive impairment (MCI)** or dementia). The contributions of this work are twofold: First, we present a novel **participatory design (PD)** methodology which allows different user groups to engage with the workshop separately while also allowing for both groups to exchange ideas in the final phase. Second, to confirm the concrete designs and themes from the workshop, these outcomes were integrated into a prototype and evaluated with older adults. This second stage is not typically undertaken in the field of human–robot interaction (see Section 2.4). The PD workshop and prototype evaluation presented in this article addresses the following **research questions (RQs)**:

RQ1: What are the barriers to older adults engaging with cognitive activities?
   (a) What strategies can be utilized to combat these?

RQ2: How can SARs and sensory feedback be integrated to foster engagement in cognitive activities?

RQ3: Does the prototype confirm the outcomes from the PD workshop with respect to the SARs and sensory feedback designs and engagement strategies as a way to promote engagement with cognitive activities?

2 Background

In this section, the need for preventative measures of cognitive decline is established, followed by a survey of CT strategies and tools. Furthermore, the literature behind the choice to incorporate SARs and sensory feedback is reviewed. Lastly, the chosen workshop methodology is supported.

2.1 CT for Cognitive Decline Prevention

CT is a targeted rehabilitation technique which aims to exercise areas of cognition that pose difficulty for an individual as well as sharpen intact areas of cognition to help support those areas of difficulty [9]. It can be delivered through a therapist via paper-and-pen tasks, or through a computer, which is called **computerized cognitive training (CCT)**.

One of the main criticisms of this technique is the limited research investigating whether this treatment generalizes [69]. However, Berry et al. [5] found 10 hours of perceptual discrimination training across 3–5 weeks resulted in improved performance at untrained working memory tasks. This was further supported neurologically through electroencephalography readings. In a randomized control trial, independently living older adults performed CT for 10 sessions lasting 60–75 mins followed by two training boosters in years 1 and 3 [67]. The reported results were taken after the fifth year in approximately 1,800 older adults. Those in the reasoning training group self-reported significantly less difficulty completing instrumental activities of daily living (e.g., grocery shopping and meal preparation) compared to the control. A review of randomized control trials of pharmacologic and non-pharmacologic means for cognitive decline prevention found CT was the only intervention that resulted in an improvement in memory [41]. In regard to CCT, the literature over the years has consistently shown that, for typically aging older adults, the intervention leads to improved cognitive performance in addition to enhancement in clinical measures of everyday functioning [24]. Therefore, not only has CT been shown to improve cognitive function over the long term, but it can also generalize to functional activities. Due to these positive outcomes of CT, it is an ideal foundation for creating technology-based activities for older adults without MCI/dementia.

CT Resources. Oftentimes CT tools are developed for other conditions and adapted for those with cognitive decline. For instance, the pen-and-paper CT program *Brainwave-R* [33] was originally developed for brain injury, but this tool shows promising results across multiple dementia case studies [21, 55]. It has further been implemented by occupational therapists who work with those with dementia (evidenced by interviews with therapists).[1] A CCT tool named *RehaCom* [28] has been shown to improve cognition in addition to balance in healthy older adults. Another CCT platform, *My Brain Training* [40], offers users to work with a clinician to determine and adapt their program. A theme throughout these tools is they consist of exercises targeted to specific areas of cognition. For instance, Brainwave-R is made up of five modules: memory, attention, information processing, visual processing, and executive function.

2.2 SARs

SARs have the potential to improve engagement with CT interventions [34, 46]. However, a great deal of the current research regarding SARs and cognitive decline focuses on those who have MCI/dementia [26, 34, 46]. These populations require different design features based on the level of cognitive impairment [26]. This highlights the need for more research into using SARs in the context of CT for typically aging older adults.

Social engagement has been identified as a factor in delaying cognitive decline [11], and with respect to the recent COVID-19 pandemic, SARs can provide social interaction while limiting human contact. They can also assist with cognitive assessment, which has the potential to aid in early identification of MCI/dementia [14]. Previous findings have indicated acceptance among older adults toward using SARs for preventative purposes [32].

In the rehabilitation setting, an SAR resulted in increased performance and engagement compared to a virtual agent of the same robot, suggesting the physical embodiment of the system is an important factor in engagement [64]. Even for older adults with MCI, SARs were found to be more engaging compared to a tablet in the context of serious game-based CT [34]. One experiment comparing virtual reality to a physically embodied SAR for short-term CT intervention found a preference for the virtual reality across younger and older adults [10]. However, the tasks completed by the SAR (yoga exercises, dancing) were very different from those delivered through virtual reality (diving underwater, flying an airplane), and it is unclear how this impacted the outcome.

[1]These interviews with therapists were conducted by the lead author prior to this work.

Furthermore, the embodiment of different SARs can impact the resulting interaction [30, 57], which has motivated the current workshop to assess two SAR embodiments.

2.3 Sensory Feedback

In this article, we define sensory feedback to consist of visual, auditory, and haptic feedback. Sensory perception declines with age, which emphasizes the need to develop technology which can engage older adults through differing sensory pathways in order to maximize its usability and accessibility [36]. In this way, the interactions can be personalized to the individual based on areas of sensory impairment and user preferences. Incorporating a variety of sensory feedback modalities provides different mechanisms through which to deliver real-time feedback to the user (e.g., visual, auditory, haptic), which in the rehabilitation space has been shown to improve both engagement and performance [51]. SleeveAR, an augmented reality system developed for stroke rehabilitation, used different types of feedback to convey different pieces of information to the patient. Visual feedback provided real-time motion tracking of the exercise, haptic feedback delivered via a wearable device indicated erroneous movements, and auditory feedback designated when the user should stop the exercise. In this way, sensory feedback can limit workload by transmitting content across multiple modalities [66]. However, it is vital the feedback is tailored to the context in which it is applied to avoid cognitive overload [65]. For instance, Qian et al. [47] found multi-modal auditory and haptic feedback to be more effective than unimodal feedback at retaining and altering walking speed for older adults. Another study looking at unimodal and multi-modal auditory and haptic feedback in the context of a memory activity with SARs found unimodal auditory feedback resulted in higher performance, higher usability, and was preferred by older adults [42]. This was attributed to the tactile and visual-spatial nature of the task, where these sensory channels were potentially overloaded, rendering auditory feedback most useful. To the authors knowledge, the research up to this point has not taken a user-centered design approach to directly investigate the integration of sensory feedback into CT tasks to improve engagement.

2.4 PD

The PD methodology was chosen for this workshop because it allows the users to become co-designers, diffusing the asymmetry of power between the researcher and the stakeholders [27]. For older adults, it is particularly important to engage them early and often in this design process [31]. This active engagement is important for ensuring the outcomes support the needs of the target user group [6], and in many cases, engaging other stakeholders into PD can assist in meeting this goal. PD workshops that incorporate multiple user groups often separate the groups across different workshops [13, 25, 49, 63]. Meiland et al. [38], on the other hand, held workshops that combined professionals with persons with dementia as well as professionals with informal caregivers during certain phases. This manuscript will present a novel methodology that will separate the user groups through most of the workshop and allow them to collaborate at the end of the session.

Furthermore, PD has successfully been used in the context of SARs and healthcare across user groups including older adults [39, 44], stroke survivors [13, 20], and individuals with Parkinson's disease [25]. However, much of the PD research in the area of human–robot interaction stops after the design phase (e.g., [13, 49]). This research will take the outcomes of the PD workshop a step further by validating the concrete themes and designs through a user evaluation of a resulting prototype.

2.5 Literature Summary

While the generalizability of CT is a topic of debate, there is a great deal of literature to support its positive influence, particularly as a preventative measure for cognitive decline. However, there are access and engagement barriers such as the availability of resources and difficulty motivating that can limit the potential impact of this therapy. Technological resources have the potential to combat these barriers. Incorporating an SAR with sensory feedback would provide another potential technological resource that can enhance engagement through social means, which led the authors to design this PD workshop and prototype evaluation.

More specifically, two SARs are presented in this workshop because the robot's embodiment can significantly impact the interaction with the user [57]. To the authors' knowledge, direct comparison between SAR embodiments in a PD workshop is not something that has been explored in the context of cognitive activity engagement. Furthermore, in addition to the more common use of visual and auditory feedback, haptic feedback has the potential to improve performance and engagement in the resulting system.

This work contributed a novel PD methodology in which we engaged multiple user groups to identify the current barriers to CT engagement for older adults and how the target technologies may be integrated to address them. The second main contribution of this work was to confirm the outcomes of the workshop through a prototype evaluation with our target user group. To achieve this, the designs and engagement strategies were integrated into a prototype and evaluated by older adults. The rest of this article will review the two phases of this work.

3 PD Workshop

3.1 Methodology

3.1.1 Participants. This workshop received full ethical approval by the Heriot-Watt University. Older adults and therapists were recruited via e-mail through professional connections to organizations and groups (e.g., local housing associations). Participants were provided travel reimbursement and catered lunch as a thank you for taking the time to engage in the workshop. Two sessions of the workshop were held, and participants were asked to attend one of the two. The first workshop consisted of one group of four older adults and another group of three therapists. The second workshop consisted of one group of five older adults. While there were no therapists in the second day of the workshop, the protocol remained the same. Thus, there were a total of nine independently living older adults ranging in age from 67 to 82 (M = 73.5, 1 male and 8 females). Five of the participants currently or previously worked in the area of health and social care. In terms of technology use, mobile phones were most often used, followed by television, computers, tablets, and video games, respectively. All nine individuals had interacted with SARs once in a previous study associated with this research [43].

The therapist group consisted of an occupational therapist, a speech language pathologist, and a clinical neuropsychologist, all of which had 5 or more years of experience. They had worked with individuals with MCI and dementia throughout their time as therapists, in addition to other neurological conditions. Two of the three therapists had not interacted with SARs previously. Computers were most often used in their practice, followed by touch screen mobile phones. While this research targets older adults prior to needing to interact with a therapist, including this group allowed us to attain how they motivate and engage their patients, and this could carry over to the prototype. Furthermore, they could confirm whether these kinds of activities are used in practice and would be beneficial for the goals of this work.

3.1.2 Protocol. Participants filled out the consent form and preliminary questionnaire prior to the workshop. The older adults and therapists were placed in separate groups until the presentation and feedback session. Each group contained a discussion facilitator and a scribe who took detailed notes on participants discussions throughout the workshop. All scribes and facilitators had experience in the area of human-robot interaction or related area of human-computer interaction and were

Table 1. Workshop Protocol Overview

Phase	Duration
Introduction	10 mins
Past Experience	15 mins
Scenarios and Personas	15 mins
Demonstrations	30 mins
Design Session	20 mins
Presentation and Feedback	30 mins
Total (not including breaks): 2 hours	

Although not shown, breaks and a catered lunch were integrated throughout.

familiar with PD methodologies. The workshop lasted 1 hour and 10 mins, not including the breaks and catered lunch. The full breakdown can be found in Table 1, followed by an in-depth discussion of each phase.

Introduction. The researcher presented background knowledge of the research and the aims of the workshop.

Past Experience. In previous works (e.g., [2, 61–63]), this information has been gathered to provide insight into participants' opinions regarding rehabilitation materials/regimes. Uzor et al. [63] used this technique with those who had not engaged in rehabilitation after a fall, therefore indicating that direct experience is not necessary to provide insightful feedback on current practices. In the context of this research, it is important to establish a baseline of older adults' current practices with respect to cognitive activities in order to identify factors that impact engagement.

In this workshop, a series of CT resources were presented to provide context for the range of current and potential administrations of CT including paper-based, computerized, and robotic.

- *Brainwave-R:* [33] Executive function module, moves on a maze puzzle, pen-and-paper resource (Figure 1).
- *RehaCom:* [28] Attention and concentration module overview, computerized resource.[2]
- *My Brain Training:* [40] Logic puzzle "Cog Trails," computerized resource.[3]
- *Nao:* Memory game [43], robotic application.[4]

User group-specific questions were used to guide this discussion (Appendix A.1). The older adults' questions centered around their current engagement in cognitive activities, and the therapists' questions were about current CT practices used with their patients.

Scenarios and Personas. Scenarios and personas have been utilized to promote engagement in the discussion, and it has been previously used with older adults [44, 62, 63]. To encapsulate variation in user experience, scenarios can be employed to provide a concrete foundation for discussion [63]. This can help to identify barriers to engagement in contexts outside of the participant's individual experiences. As part of the scenario-centered design technique, personas have been used to guide the design of robotic systems in relation to activities of daily living [15]. Participants can refer back

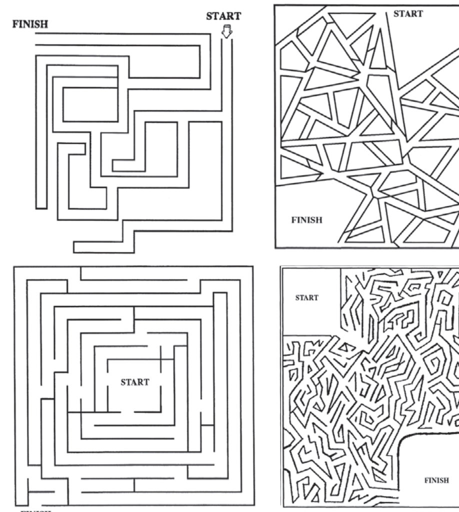
[2]https://youtu.be/pMwgWHRe5sE?si=U5muWxeprvR-Gdbw{&}t=90
[3]https://www.youtube.com/watch?v=Lp1MkGraW5o
[4]https://www.youtube.com/watch?v=wBr0-CQEYLU

Say:

Planning is another important aspect of executive skills. One way to improve in this ability is to speak your plans out loud. This seems strange at first, but it really does work. As you improve, you can start to speak silently to yourself. This approach helps you to slow down and be methodical in your approach to planning. Each of the eight worksheets contains a maze. When you do the mazes, follow these rules:

- *Do not lift your pencil off the paper until the end.*
- *Pause at every point in the maze where there is a choice of direction.*
- *Tell me which way you are going to go before you do it.*

(a)



(b)

Fig. 1. Brainwave-R executive function module maze activity (a) instructions (b) example mazes. Images from [33].

to personas throughout the workshop, and they can be utilized to circumvent potential feelings of discomfort in discussing one's personal experiences [63].

For this workshop, scenarios and personas were used to discuss challenges and means to engage individuals along the spectrum of cognitive decline. The personas exemplified typical aging (Alice), MCI (Bob), and dementia (Riley). A female, male, and gender-neutral presenting name was chosen to exemplify a range of gendered personas, which is commonly employed in PD workshops that integrate personas (e.g., [63]). Furthermore, the areas of difficulty identified in Figure 2 are linked to difficulties in cognition, which are not inherently linked with any specific gender. The characteristics of each persona were chosen from common presentation of the different levels of cognitive decline. Specifically, early indicators of decline for typically aging older adults include memory difficulties [12]. Those with MCI often experience difficulties with more complex everyday activities such as food preparation, termed instrumental activities of daily living [1]. Symptoms relating to dementia have a more severe impact on their day-to-day life and can include confusion and more severe memory difficulties [8]. The group facilitator systematically reviewed each scenario listed below, inviting participants to discuss the challenges that each persona might encounter within the given contexts.

— *Alice* is engaging with cognitive activities in her everyday lives, both through pen-and-paper and mobile phone/tablet devices (e.g., Sudoku, crossword puzzles, jigsaw puzzles, My Brain Training app).
— *Bob* is engaging in daily exercises from a CT therapy booklet (e.g., Brainwave-R).
— *Riley* is engaging in daily exercises from a computerized CT therapy tool (e.g., RehaCom).

Demonstrations. Demonstrations are particularly important in this process when introducing unfamiliar technologies to the participants (e.g., SARs, haptic devices). They have been used in previous PD workshops with respect to rehabilitation with SARs [62, 68]. This allows participants to understand the capabilities of the technology, forming mental models that will carry into the subsequent design session. In this phase of the workshop, the groups rotated through three

Personas		
Alice	**Bob**	**Riley**
• Aged 68 • Experiencing 'typical' cognitive decline	• Aged 75 • Has mild cognitive impairment	• Aged 82 • Has dementia
	Example areas of difficulty	
➢ Trouble remembering to take their medicine before going to bed	➢ Trouble following the story of TV programmes ➢ Difficulty cooking a balanced meal	➢ Oftentimes repeats the same question ➢ Struggles with feeling disoriented (impacts their day-to-day life)

Fig. 2. Personas: This handout was given to participants during this session.

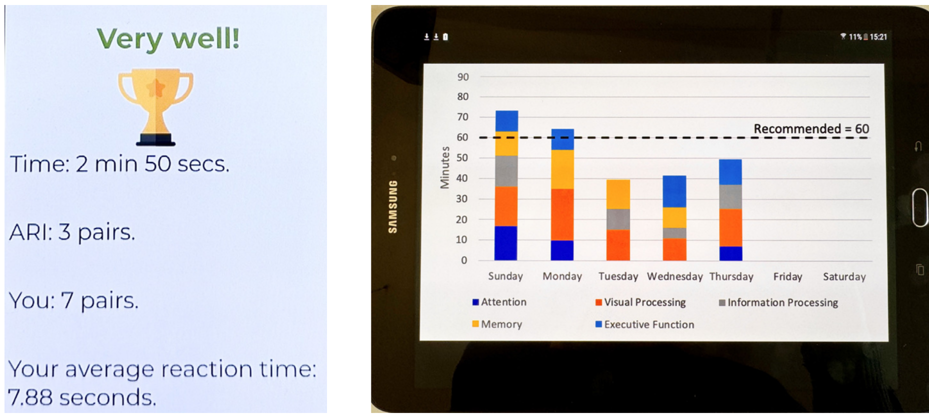
(a) (b)

Fig. 3. Demonstrations. (a) Telegram activity with Nao. A participant holds the tablet with the activity on it while listening to the robot explain the activity. (b) Card matching activity with ARI. It displays a participant tapping the cards on the robot's tablet.

demonstrations, where they were given the opportunity to engage directly with the technology, as shown in Figures 3 and 5.

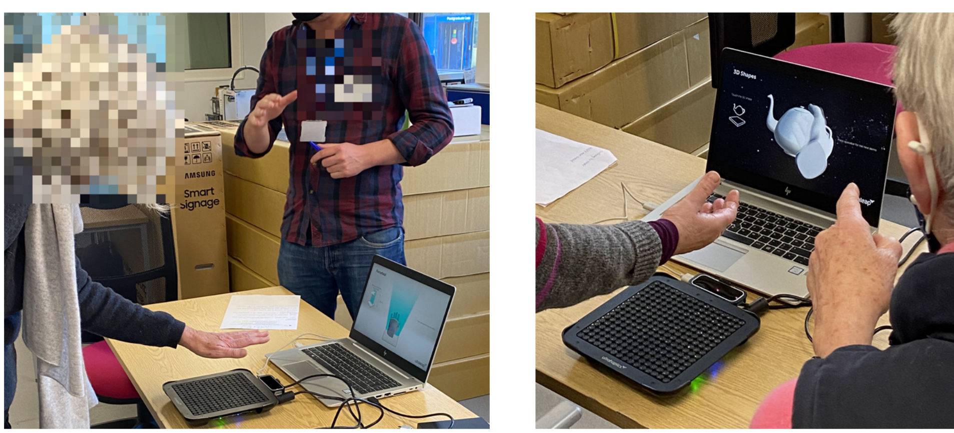
SARs. Two SARs were utilized to determine whether there was a preference for a certain type of embodiment: Nao (Figure 3(a)) and ARI (Figure 3(b)). In addition to the apparent difference in size, the platforms also differ in other factors such as voice, tablet integration, and physicality of the interaction (i.e., standing versus sitting).

The cognitive tasks facilitated by the SARs were chosen from Brainwave-R [33]. The Telegram activity, delivered through Nao, was from the executive function module. The user is asked to use the tablet to type a summary sentence, or telegram, based on a given paragraph. The card matching activity, delivered through ARI, was from the memory module. It asked the user to match pairs of 20 red playing cards, ace through 10, by tapping the integrated screen on the robot. In both cases, the robots verbally instructed the participants with how to do the activity and facilitated the tasks accordingly. The robots also asked the users to rate their predicted/actual performance prior and upon completion of the task. These pre- and post-ratings came directly from the Brainwave-R



(a) (b)

Fig. 4. Feedback shown after the (a) Telegram activity with Nao and (b) card matching activity with ARI.



(a) (b)

Fig. 5. Demonstration—Haptic feedback device.

handbooks. Finally, feedback was provided to the user. For ARI, a golden cup was displayed along with numerical scores indicating the number of pairs each player attained (Figure 4(a)). For Nao, an example bar graph depicting long-term data was shown to demonstrate how one activity could be portrayed with respect to their broader performance and to encourage participants to think about the interaction as a part of a larger longer-term intervention (Figure 4(b)).

Haptic Feedback. Haptic feedback was delivered through the Ultraleap STRATOS Explore device (Figure 5). It consists of a hand tracker and a Haptic Array that emits ultrasonic feedback. Depending on where the users hand is positioned and where they are meant to feel the feedback on their hand, certain emitters in the Haptic Array will deliver feedback. As seen in Figure 5(a), the demonstration allowed the participant to perceive a line of feedback on their hand that shifted accordingly as they moved their hand forward and backward. The device also walked the participant through feeling a series of objects (e.g., the teapot shown in Figure 5(b)) and demonstrated different functional interactions (e.g., pressing a button to turn on a light bulb).

Design Session. In the context of this work, the goal of this phase is to obtain methods and features that can be incorporated to make the proposed CT system more engaging. Sketches and annotations are a common PD strategy used to engage participants' in designing systems [2, 63]. Sometimes materials are also provided in addition to colored pens/paper, such as clippings of technology or cartoon images [44, 58], to assist in the sketching process.

Each group of participants in this workshop was provided papers containing two CT activities across various modules of Brainwave-R (separate from the ones used in the robot demonstrations). One activity which will be discussed through the rest of this article is the Category Checker activity. This visual processing task asks the user to circle the items on a list that are categorized correctly. Participants were asked to make one or both of their provided CT activities more engaging using any of the technologies from the demonstrations. They were allowed to work alone or with others in their group. In addition to colored pens and blank paper, paper clippings of ARI, Nao, and the haptic feedback device were supplied so participants could build on them through drawings and annotations as in [44]. A sheet of questions was given as a reference to what they would be asked to discuss in the next phase of the workshop (i.e., what task(s) they chose to integrate, what robot(s) and sensory feedback they incorporated, and how they made the task more engaging).

Presentation and Feedback. PD workshops typically engage multiple user groups/stakeholders by holding separate workshops (e.g., [13, 25, 49] or combining them throughout certain phases [38]. The current PD workshop is novel in that it separates the user groups throughout most of the workshop, which allows each to develop their ideas without influence from the other group. It is during this phase, the final phase, that the two groups are brought together, allowing for ideas to be shared across all participants.

In this phase, participants presented their designs to the room, and they were told they could refer to the list of questions they were given at the start of the design session to assist in their explanation. Those in attendance were encouraged to comment on the designs. This phase allowed for the cross-collaboration of ideas across all in attendance. On the first day of the workshop that consisted of both user groups, they engaged in the workshop separately without influence from the other, and this phase allowed ideas to be exchanged across user groups. The second day of the workshop had a single user group comprised of five older adults, and these participants were also encouraged to share their designs with others present.

3.1.3 Data Analysis. The notes from the scribes and the participant's designs were analyzed using the constant comparative method of grounded theory [22]. It is ideal for the data attained through this workshop because we do not know the themes prior to the analysis, and this methodology allows themes to emerge based on direct comparisons of the data. Due to the iterative nature of this methodology, inter-rater reliability is not required and is not typically incorporated [37]. However, to provide further support for the results of this analysis, 20% of the data was coded by a fellow researcher experienced in this technique. The outcomes were compared by the lead researcher, and any discrepancies were discussed with both parties and resolved collaboratively. This section will review the main themes from the analysis, and the numbered items will be referenced when discussing the resulting prototype in Section 4.

3.2 Results

This section will review the main themes from the analysis, and the bolded items will be referenced when discussing the resulting prototype in Section 4. An overview of all the themes in addition to which ones are carried over to the prototype can be found in Appendix A.2.

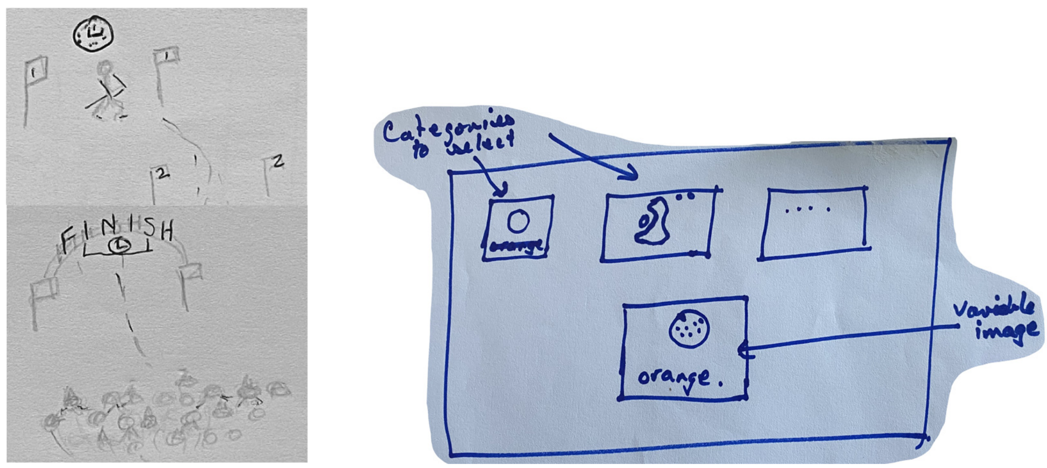
3.2.1 Past Experience. Much of older adults cognitive activity engagement lie under the category of **games** (e.g., Sudoku, bridge, chess, and shape/block apps). Other activities included puzzles (crosswords and jigsaws) and learning-based activities (language and mathematical). Participants also used a combination of pen-and-paper and technological platforms (e.g., computers and mobile phones) to engage with these activities. The therapists practice similar CT activities (e.g., paper mazes) in therapy sessions and encourage their patients to continue the activities between sessions. They recommend apps to their patients and loan out technology if that is an available resource through their place of work. One of the main benefits identified for technological resources was that they provide instant feedback.

There were many different motivational factors provided for participating in cognitive activities. Some of the older adults engage with cognitive activities in order to maintain their cognition, out of boredom, to challenge themselves, and based on the level of enjoyment attained from the task. Others did so to learn, such as learning a language. Another important motivational factor was the **diversity of the task**, for instance through variation within the activity each day. There was an indication of fear toward formal tasks, with one older adult finding "the thought of that [is] scary." Therefore, framing the task in an **informal** way can help engage older adults. The therapists personalize the rehabilitation program to motivate their patients. However, the therapists noted sometimes the standardized CT tasks can be seen as infantile, which should be avoided in the system design.

3.2.2 Scenarios and Personas. There were three main barriers to engaging with cognitive activities identified in this phase of the workshop. First, the older adults cited **aspects of the technology** that can make engaging difficult, including small screen size. Second, both therapists and older adults mentioned the learning curve was a barrier to interacting with technology. This was observed during the demonstration session, particularly with the haptic feedback device whereas the participants had no experience interacting with such technology. The third main barrier discussed was physical and cognitive challenges. The challenges discussed for the personas experiencing MCI/dementia were organizational/planning difficulties and disorientation. The challenges described for the typically aging older adult persona, Alice, were memory difficulties and difficulty adapting to change. The results from this section were focused around specific difficulties the personas might face, and we did not identify any impact of the personas gender on the outcomes.

3.2.3 Demonstrations. Participants wanted the SAR to assist with providing instructions, feedback, **encouragement**, and **prompting** (i.e., through speech or gestures). The participants also wanted the robot to be involved in the task as either a competitor or companion. Slowing down the pacing of the task as well as the speed of the speech were identified as factors that would improve the interaction. For instance, one participant found ARI took its turn too quickly during the card matching game, which "gave them less time to think." Regarding the SARs embodiments, ARI's voice was preferred over Nao's, which is likely due to the comparatively natural quality of ARI's voice. Participants also appreciated ARI's integrated tablet.

With respect to sensory feedback, some participants suggested delivering the same information through multiple modalities. For instance, one participant designed both an auditory and visual cue to indicate correct/incorrect inputs. Another participant thought adding a visual representation of sounds during an auditory-based activity would make the interaction more engaging. Other participants felt incorporating multiple types of feedback could be overwhelming. Many sketches referred to a cue having the potential to be delivered through different modalities. More than one type of the same feedback was also incorporated during the design, as in Figure 6(b), where the image of the objects also includes the word written below. Particularly for prompting and providing feedback, it was thought both visual and auditory modalities should be used. Many also mentioned



(a) (b)

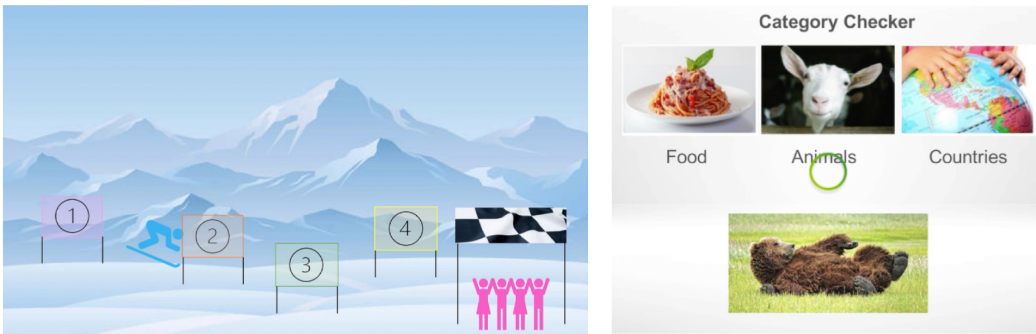
Fig. 6. (a) This participant came up with their own ski slalom game. (b) Adapted from the Category Checker CT activity discussed in Section 3.1.2.

the importance of good, “fun,” visuals. The most common integration for the haptic feedback device was to use the hand tracker to execute the task rather than it be used as a passive method for delivering haptic feedback.

3.2.4 Design Session. First, participants identified **adaptation**, particularly of the difficulty level, as a key trait toward fostering engagement. This can also fall under the theme of **task diversity**, for instance, through changing the categories in the Category Checker activity. One of the main findings in terms of engagement strategies is gearing toward **success**. For instance, activities should not contain negative symbols (e.g., “X”) nor have a time constraint. The system should guide the user to the correct solution and highlight successes. This goes along with **prompting**, which can be used to re-engage the user and provide auditory and/or visual hints. This idea of success can also be achieved by offering **encouragement** throughout the session. Additionally, **rewards** should be provided, and the user should be given the **autonomy** to choose the rewards. Some examples from participants include family photos and visual/auditory displays (e.g., flowers, fireworks, champagne, music, a gold cup, and a crowd cheering).

3.2.5 Presentation and Feedback. With respect to the novel methodology, the researchers observed the user groups working separately throughout the majority of the workshop, followed by the cross-collaboration of ideas during this phase. For instance, someone from one user group would present an idea, and others either confirmed they liked it or built on the idea (e.g., when rewards were mentioned, other participants spoke up about rewards they would prefer).

Different trends were identified in how participants altered the CT tasks during the design and feedback sessions. Generally, the introduction and conclusion should be visually **fun and colorful**. The SAR should welcome the user to the session in a different way each day. If it is not the first session, it should also review the last session, highlighting successes and progress. Activity introductions should have clear, step-by-step instructions in addition to a **video demonstration**. The activities themselves should be diverse by providing customization options. The therapists suggested making the tasks more functional where possible to translate more to their everyday lives. Upon completion of a task, the user should receive their reward, which, as discussed previously



(a) (b)

Fig. 7. Digitized versions of the sketches in Figure 6. (a) The skiing design is used as a motif shown at the start and end of the session to indicate progress. (b) Category Checker with the haptic feedback device. The green circle is the cursor which is moved using the device's hand tracker.

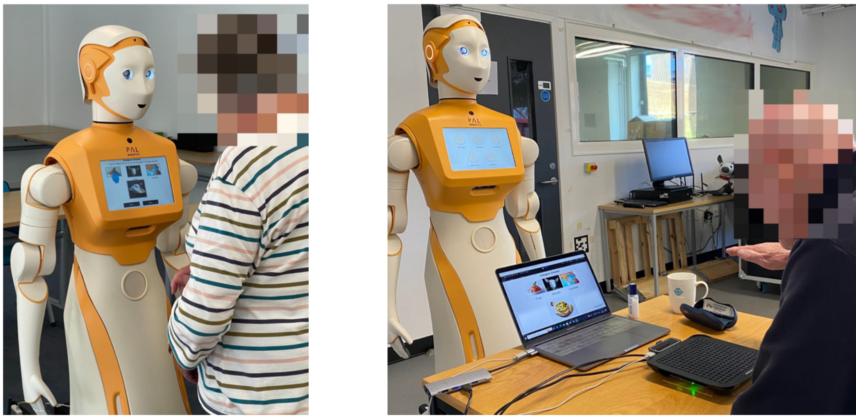
(Section 3.2.4), should be of the user's own choosing. The pre- and post-activity self-ratings were seen as potentially discouraging, so one solution offered was to make it optional. Direct feedback on one's performance and long-term progress should be displayed visually in the form of **graphs/charts** and through an auditory message from the robot. At the end of the interaction, the system should recap the session and provide a plan for the next session.

4 Prototype

In order to confirm (or deny) the results from the PD workshop, we developed a prototype that incorporated the themes and concrete designs discussed in Section 3.2. The design for the Category Checker activity was chosen for this next experiment because multiple participants in the workshop drew very similar designs (an example is shown in Figure 6(b)). Further, the activity was implemented onto ARI's tablet and on the haptic feedback device in order to compare both interaction mechanisms, with a particular focus on the impact of integrating this kind of haptic feedback. This section describes how the designs and themes were brought together into a prototype. The headers align with the protocol described in Table 2, and the bolded items correspond to the ones found in Section 3.2. Appendix A.2 reviews all themes found in the PD workshop and indicates which were carried over into the prototype, including all eight engagement strategies.

Prototype Introduction. The robot welcomed the user to the session using the **colorful** skiing motif (Figure 7(a)) from the sketch created during the workshop (Figure 6(a)). This introduces the user to the session in an **informal** way. It then walked them through a set of **rewards** they could choose from. The fireworks and popping champagne were chosen for them in this prototype. A set of activities were then shown, and the Category Checker was pre-selected. They were provided with an **instructional video** of the activity, which also told them they should try to complete the task both quickly and accurately. This was followed by options on how the task could be **adapted** (e.g., show the object to be categorized as text, image, and sound, rather than just image). Before starting the activity, the robot asked the user to rate how well they think they will perform on a scale from 1 to 5. Participants had the option to skip this, as discussed in Section 3.2.5.

Category Checker Activity. This activity required the user to select the category from the top row that corresponded to the image at the bottom of the screen. The initial design can be found in Figure 6(b), and the digitized version is shown in Figure 7(b). To perpetuate the theme of **success**, if an incorrect category was chosen, the user could keep trying until they guessed correctly. During



(a) (b)

Fig. 8. Category Checker interaction modalities. (a) ARI's tablet. (b) Haptic feedback device.

the activity, the robot said two phrases of **encouragement** (e.g., "keep going" and "almost there") followed by the **prompt** "all done" when the set of 27 images had been categorized.

There were two means of interacting with the activity: using the robot's tablet and through the haptic feedback device (Figure 8). This exemplifies **task diversity** by providing another form of interaction. When using the robot's tablet, a "ding" sound was played each time the correct category was selected. With the other device, haptic feedback was delivered throughout. The user selected an answer by hovering the cursor over a category for one second. When the green cursor (Figure 7(b)) got close to a category, it would snap to the center of the image. The haptic feedback changed from a singular point of feedback on their palm to a circular motion, similar to a loading cursor or progress bar, while the center of the cursor turned orange over the course of one second.

Upon completion of the activity, a video of a firework display or champagne popping was then played as a reward. This kind of animated reward is a common **gaming** element. They were then asked to fill out a post-rating of how well they thought they performed, followed by a question of whether they wanted to receive feedback on the activity. If yes, the feedback page consisted of the task duration, number of errors, and, if they filled them out, the pre- and post-rating scores.

Conclude Prototype Interaction. The participant was then presented with a screen where they could choose what to do next to exemplify user **autonomy**. Finishing the session led to a screen with a **bar chart** similar to the one described in Section 3.1.2, and the robot provided positive feedback. The final screen showed the skiing motif from the initial welcome. The robot stated it is "looking forward to seeing them next time, where we'll focus on memory activities." Then an animation is played where the skier moves through flag two while the crowd jumps and cheers (Figure 7(a)).

5 Prototype Evaluation

5.1 Methodology

5.1.1 Participants. This experiment received full ethical approval by the Heriot-Watt University. Participants consisted of eight independently living older adults aged 67 to 83 ($M = 74.3$, 4 females and 4 males), five of which had participated in the previous workshop. We invited those outside the workshop to ensure any acceptance of the prototype was not biased due to having been involved in the initial design. The external participants were recruited via e-mail through professional

Table 2. Prototype Evaluation Protocol

Phase 1: Prototype Interaction	
Prototype Introduction	5 mins
Category Checker: Robot's Tablet	5 mins
Evaluation Measures	10 mins
Category Checker: Haptic Feedback Device	5 mins
Evaluation Measures	10 mins
Conclude Prototype Interaction	5 mins
Godspeed Questionnaire	5 mins
Break	10 mins
Phase 2: Feedback Session	
Prototype Review	25 mins
Total (not including the break): 1 hour 10 mins	

The phases highlighted in blue were counterbalanced across participants.

connections to relevant groups and organizations. Two of the remaining three did not have any previous experience with humanoid robots, and the other had interacted with the Nao and Pepper robots once. Each participant received a 10 voucher as a thank you.

5.1.2 Protocol. As in the PD workshop, participants filled out the consent form and preliminary questionnaire prior to arrival. All participants interacted with the Category Checker using the robot's tablet and the haptic feedback device, and these conditions were counterbalanced across participants. The participants were allowed to try out the activity with the haptic feedback device prior to the official trial to get comfortable with the device. This is because the researchers observed during the PD workshop that there was a learning curve to figuring out, for example, where to hover their hand over the device to feel the haptic feedback. This training also gave them a chance to decide whether to sit or stand, depending on what was comfortable for them. The reward provided after the task (fireworks and champagne) were counterbalanced across participants. The researcher documented observations during phase 1 (Table 2) and took notes on feedback from the participant during phase 2 to be analyzed afterward using the constant comparative method [22].

Evaluation Measures. The following evaluation measures were given after each interaction with the Category Checker activity.

— *NASA* ***Task Load Index (TLX)*** [23] to assess workload.
— *Emotion wheel* [3] to assess their emotional status.
— ***Intrinsic Motivation Inventory (IMI)*** [52]. The following sub-scales were assessed: interest/enjoyment, effort/importance, pressure/tension, and value/usefulness.

Godspeed Questionnaire. This questionnaire was given in order to assess participants' perspective of the robot.

Prototype Review. Participants received a packet where each "slide," or page, displayed an image of what was on the robot's screen accompanied by a written description. They were asked to rate their perception of each slide on a scale from 1 (negative) to 5 (positive). Then they would mark on the slide any elements they liked with a checkmark and any elements they did not like with a cross ("X"). An example of a filled out slide can be found in Figure 9. The researcher asked participants to

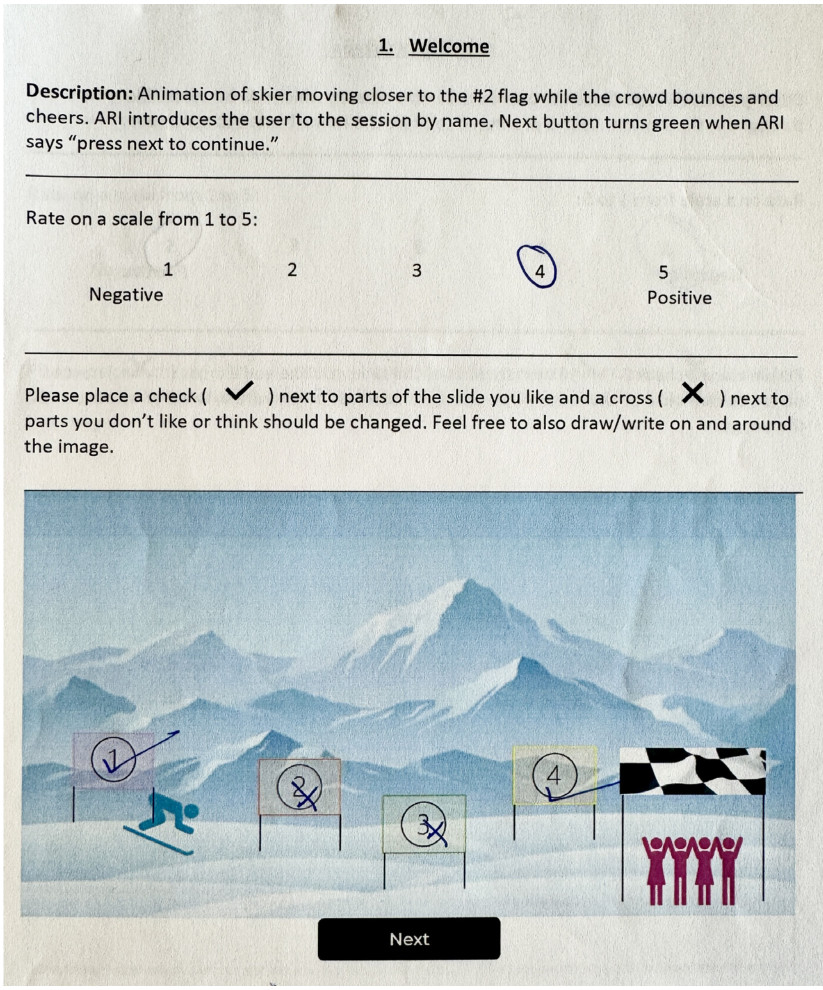


Fig. 9. Example of a filled out slide from the prototype review phase of the protocol.

explain their choices when filling out each slide in the packet and took notes on their responses. This methodology has been used previously by [53].

5.1.3 Data Analysis. For the quantitative data collected, descriptive statistics will be reported whereas the sample size was not large enough to support statistical testing. Data collected during the prototype review (comments on slides and notes taken by the researcher) were analyzed using the constant comparative method of grounded theory using the same procedure discussed in the PD workshop (Section 3.1.3).

5.2 Results

5.2.1 Phase 1: Prototype Interaction. Participants completed the Category Checker activity quickly and accurately (Table 3). All eight participants rated themselves either the same or higher in their post-activity rating compared to their pre-activity rating (Table 3).

Table 3. Participants' Average Performance Scores at the Category Checker Activity across Conditions

	Duration (s)	Number of errors	Pre-rating (out of 5)	Post-rating (out of 5)
Robot's Tablet	41	0.5	4.3	4.6
Haptic Feedback Device	130	1	4.1	4.4

For the pre- and post-ratings, a 5 indicates that they believe they will perform/performed very well at the activity.

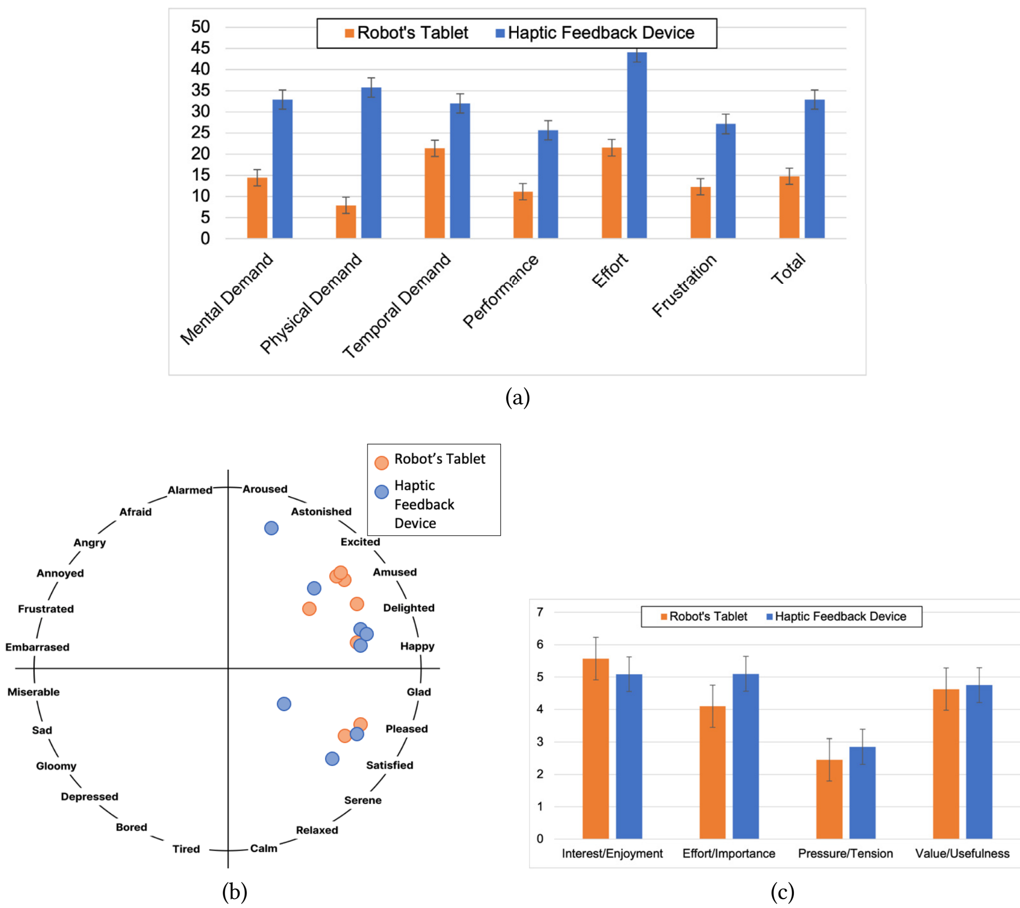


Fig. 10. Outcomes of the evaluation measures. (a) NASA TLX, (b) emotion wheel, and (c) IMI. The error bars represent standard error.

Participants were given a choice with the haptic feedback device to sit or stand, and five out of eight chose to sit. Five participants found the feedback difficult to perceive. The other three participants said they really felt the feedback, two of which were female. For one participant who did feel it, they stated, "I can feel tingling" and "you felt you connected when you got it right."

The NASA TLX showed increased workload with the haptic feedback device across all sub-scales (Figure 10(a)). However, all data points from the emotion wheel (Figure 10(b)) were on the right half (toward very positive), 69% of which were in the upper right quadrant (very active/very positive). Lastly, the IMI (Figure 10(c)) showed relatively high scores across interest/enjoyment, effort/importance, and value/usefulness, and relatively low pressure/tension scores. The robot itself also received positive scores, evidenced by the Godspeed questionnaire ($M = 4$ out of 5). The anthropomorphism and animacy sub-scales received an average score of 3, and the likeability, perceived intelligence, and perceived safety scale received an average of 4.

5.2.2 Phase 2: Feedback Session. The Likert scale across all slides resulted in an average score of 4.40 out of 5. Particularly, an average rating of 5 was given to the introductory videos, pre- and post-ratings, and the reward videos. Nine of the 19 slides allowed for user choice and autonomy, and the average score across these slides (4.56) was higher than the overall average. There were also substantially greater check marks (173) drawn compared to crosses (23). It is important to note with these results that the sample size was not large enough to facilitate statistical testing. The rest of this section reports the main themes from the resulting constant comparative analysis [22].

Personalization. Differences in opinion with respect to certain facets of the prototype indicated a need for personalization of the system. First, a few participants found ARI's encouragement during the activity distracting, although one participant who liked the verbal feedback said, "it helped me because I wasn't sure if I was near the end." Regarding the rewards, some did not think they would use this feature, and others found it engaging. One person said it "makes people feel that they're part of a celebration of some kind" and "it's something special." Regarding the skiing motif for the welcome and conclusion, participants suggested other options more relevant to them such as soccer, running, and horseback riding. A few participants additionally mentioned the need for personalization based on someone's area of sensory impairment.

Autonomy. The theme of autonomy emerged whereas participants wanted the ability to exercise control over the interaction. For example, the activity customization pages were well received. One participant said, "the customization might be quite important if you're using it a lot. The more customization you have, the more interesting it would be for the user." Another said they would use it to increase difficulty, for instance, by going from the spoken word (e.g., dog) to the sound cue where the noise is made (e.g., barking). Along these same lines, participants appreciated being asked directly whether wanted to see feedback and being able to skip certain sections such as choosing rewards for the session or completing the pre- and post-ratings.

Learning Curve. A learning curve was prevalent, particularly when interacting with the activity using the haptic feedback device. However, this is to be expected when engaging with any new technology. With the robot's tablet, a few participants hesitated when touching the first few categories, but over time became faster and more confident.

Familiarity. Yeah Familiarity influenced what form of interaction participants liked best. One individual said, "I prefer the touch screen, but maybe that's because I am used to using touch screens." Regarding the haptic feedback device, one participant suggested changing the circular cursor to a computer arrow since this would be more familiar. Interacting with this device "demanded a lot more concentration," which is supported by the NASA TLX scores (Figure 10(a)). Another participant "found it more difficult but fun, interesting to do," which was supported by the positive outcomes for the haptic feedback device for the emotion wheel and IMI (Figure 10(b) and (c)). These difficulties encountered could have been influenced by their level of familiarity with the device.

Feedback to User. Participants generally liked having the perceptual feedback (i.e., their pre- and post-rating scores). One participant stated, "it did motivate me because I didn't think I'd do well, so I was pleased." Participants liked the graphical layout and long-term feedback, although they thought this should be simplified by removing the breakdown into the different areas of cognition. They also wanted to track their performance scores over time.

6 Discussion

This section will review in turn how each RQ was addressed by the PD workshop and subsequent prototype evaluation. One of the main contributions of this work which does not directly fall under the research questions is the efficacy of the novel methodology in which the older adults and therapists were separated for the majority of the workshop and then joined in the last phase to share their designs across groups. Structuring the workshop in this way allowed for the user groups to engage in discussions and creating designs without influence from the other group. Where appropriate, each phase of the protocol was tailored to the specific user group (see the guiding questions for the past experiences phase in Appendix A.1). The presentation and feedback phase allowed participants to comment on others designs. This is useful in two ways. First, individuals could show their support for other participants ideas, allowing the researchers to attain a better perspective of which aspects of participants' designs are most important. Second, participants could make suggestions to add to others designs, therefore enhancing collaboration across all in attendance. Even in the second day of the workshop which only consisted of one user group, these two benefits were also observed. This novel PD methodology would be useful for future research by allowing for different user groups to engage in PD workshops without influence from other groups, while still facilitating the exchange of ideas in the final phase. The rest of the discussion will address how the three research questions have been answered.

RQ1: What Are the Barriers to Older Adults Engaging with Cognitive Activities, and What Strategies Can Be Utilized to Combat These? The PD workshop identified aspects of the technology and the learning curve as barriers to engagement. While we cannot alter the size of ARI's tablet, the size of text can be increased, the pace of the interaction can be adapted, and video demonstrations can be incorporated. Instructional videos were used in the prototype, and they received very positive ratings (Section 5.2.2). Furthermore, familiarity can be leveraged to limit the learning curve, which could also reduce the difficulty of adapting to change identified with the scenarios and personas in the workshop. For instance, older adults most commonly engaged in cognitive games (Section 3.2.1), and many of the designs from the workshop included gaming elements. This is supported by prior work which delved into using serious games to monitor and assess the mental state of older adults [18, 59]. For the therapist group, there was a tendency toward making their designs functional, which is commonly found in research that has involved therapists in the creation of rehabilitation games [16, 60]. The specificity of this viewpoint highlights the importance of incorporating multiple stakeholder groups into the design process to ensure high adoption by the end users.

RQ2: How Can SARs and Sensory Feedback Be Integrated to Improve Engagement in Cognitive Activities? SARs. One of the main findings through the PD workshop, and confirmed by the prototype evaluation, was that older adults want the autonomy to personalize the interaction. In human–robot interaction, mass customization has shown to have a positive impact on acceptance, enjoyment, usefulness, and intention to use in the future [29].

This workshop found participants wanted the SAR to act as a competitor or a collaborator, and this is one potential factor that could be predetermined by the user. During the demonstrations, researchers observed a positive response to a competitive environment. After competing against ARI in the Card Matching game, a few participants, unprompted, chose to play the game again, this time together against the robot. This further supports the growing literature indicating SARs can assist in multi-party engagement in the context of cognitive decline through fostering social engagement not only with the robot [45, 70] but also between humans [48].

Furthermore, aspects of ARI's embodiment were preferred compared to Nao, such as the voice and physicality of the interaction. In the prototype evaluation, the positive results from the Godspeed questionnaire supported the use of a humanoid robot such as ARI for the purpose of promoting engagement with cognitive activities.

Sensory Feedback. Visual and auditory feedback were most often incorporated into participants' designs. One way haptic feedback was incorporated was by using the device to execute the activity. The limited use of this feedback in the designs could have been due to their unfamiliarity with this type of haptic feedback. This design was integrated into the prototype and received positive feedback qualitatively and quantitatively (Figure 10 and Section 5.2.2).

Furthermore, many participants wanted the feedback to be "fun" and "colorful" in addition to framing the tasks in an informal way. However, the therapists mentioned that sometimes these CT tasks can be seen as infantile. Therefore, researchers must strike a balance between these factors when designing such a system.

Prompting, which can be delivered through a variety of modalities, was an engagement strategy identified in the workshop (Section 3.2.3), and it was also found to be an important factor in a robotic system design for individuals with dementia [35]. Mostly auditory and visual prompts were incorporated in the design session of our workshop. However, in the case of using sensory feedback to provide hints to the user to gear toward success, haptic feedback, such as through the haptic feedback device, may also be a valuable means to guide the user toward the solution.

There were some discrepancies with respect to how the sensory feedback should convey information. Similar to how SleeveAR was designed for stroke rehabilitation [54], a few participants wanted different modalities to be used to indicate different information (e.g., visual prompts, verbal reassurance, and haptic guidance). Others suggested multiple cues of the same modality (e.g., picture as well as written text as in Figure 6(b)) or the option to present a cue across different modalities (Section 5.2.2). This may be best addressed by allowing the user the autonomy to decide how they would like the feedback delivered. This would also allow for adaptation based on an individual's impairments as well as long-term adaptation as one's sensory perception declines.

RQ3: Does the Prototype Confirm the Designs from the PD Workshop as a Means to Promote Engagement with Cognitive Activities? First, the novel user group setup effectively facilitated independent discussion of ideas and design generation while also providing an opportunity for cross-collaboration during the presentation and feedback session. This is supported by observations by the researchers discussed in Section 3.2.

The main outcomes from the prototype evaluation are that the final system should be personalized to the user and provide them with autonomy in order to improve engagement. The need for personalization arose from differences in opinion regarding different aspects of the prototype, such as ARI's verbal encouragement, reward choice, and sensory feedback, as discussed in Section 5.2.2. Additionally, the sections of the prototype that allowed for user autonomy were received positively by participants. This included slides such as the choice of reward, questioning whether or not the user wants to receive feedback, and the slide that offers them the choice of what to do next. This also includes sections that can be skipped, such as the pre- and post-ratings, and feedback suggests the rewards should also have the option to be skipped. Familiarity is another factor that can be altered. While some found the haptic feedback device to be more difficult to use, some also found it more interesting. This indicates that while one mode of interaction may be familiar, it does not mean other forms should be discounted. Furthermore, the increased physicality was referenced with the haptic feedback device. It could be beneficial for older adults to have an interaction mode that incorporates more physicality, indeed prior work has found simultaneous cognitive and physical training to be the most effective at improving cognition [19].

The NASA TLX (Figure 10) showed the haptic feedback device had a higher workload compared to the robot's tablet. Specifically, it received at least two times higher workload scores across all sub-scales apart from temporal demand. However, because this was the participants' first or second time using the device, it was not clear how much the novelty impacted this outcome. Nonetheless, participants completed the Category Checker both quickly and accurately. The increase in duration for the haptic feedback device was largely due to it taking longer to move and hold a cursor than to interact with the robot's touch screen. Furthermore, most of the emotion wheel data points lay in the very positive and very active quadrant of the scale. This association between high workload through the NASA-TLX and positive indicators from other measures (e.g., affective engagement, usefulness) has been found in other work in the human-computer interaction community across multiple user groups [50, 56]. With respect to this work, the outcomes of the prototype evaluation suggest high engagement while interacting with a robot-facilitated activity, regardless of interaction modality.

The IMI results suggest low pressure/tension and relatively high interest/enjoyment, effort/importance, and value/usefulness, which indicates high internal motivation when executing the task. The scores were very close across both interaction modalities except for the slightly higher effort/importance scores in the haptic feedback condition. This is to be expected based on the NASA TLX results, although this could also indicate participants attributed higher importance to the task when using the haptic feedback device. The two could be connected, where the higher workload could lead to the user attributing higher importance to the task, which in turn could promote engagement. This aligns with older adults engaging in cognitive activities to challenge themselves (Section 3.2.1). Overall, these outcomes support the strategies and designs created in the PD workshop as a way of promoting sustained engagement with cognitive activities for older adults.

6.1 Limitations and Future Work

One limitation to the demonstration portion of the PD workshop was that the activities and activity feedback for each robot were different. This was chosen in order to exemplify different types of CT activities and mechanisms of activity feedback, but this may have impacted participants impressions of each robot embodiment. Also, only one of the two PD workshop sessions had multiple user groups, therefore the novel methodology was only able to be assessed on one occasion. A few participants misunderstood the directions during the design session of the workshop, however this resulted in interesting designs nonetheless, such as the ski slalom (Figure 6(a)). To prevent this from happening in the future, we would suggest explicitly dividing members of each group into smaller groups to encourage more collaboration and discussion prior to constructing designs. In the prototype evaluation, the haptic feedback was not strong enough to be perceivable by most participants. However, we were unable to make the intensity stronger due to a technical limitation. The next stage of this work is to conduct a long-term experiment to evaluate whether these design considerations with respect to SARs and sensory feedback can foster engagement over the long-term.

7 Conclusions

This work demonstrated how a novel combination of a robotic system with sensory feedback could be designed for older adults to foster engagement with cognitive activities. A main contribution of this work was the success of the novel PD methodology which facilitated independent participation of multiple user groups in the same workshop concluding with the exchange of design ideas across groups. This PD workshop identified strategies to improve engagement, such as providing the user with autonomy to control the interaction. It also compared two robot embodiments, one of which was chosen for the resulting prototype. This prototype directly integrated the engagement strategies and concrete designs identified in the workshop. The results support the use of either a robot's tablet or a haptic feedback device as interaction modalities to foster engagement. The results further suggest that increased workload, such as that found with the haptic feedback device, may not negatively impact engagement. The prototype evaluation is the second main contribution of this work because it allowed us to experimentally confirm the designs and engagement strategies identified in the workshop. The next stage of this research is a long-term evaluation with typically aging older adults to assess whether the system promotes sustained engagement with cognitive activities.

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Appendix

A Participatory Design Workshop

A.1 Past Experience—User Group Questions

A.1.1 Older Adults

(1) What cognitive activities do you engage with?
(2) What tools/technologies, if any, do you use to engage with these cognitive activities?
(3) What motivates you to engage in cognitive activities?
(4) What barriers do you face toward engaging in cognitive activities?

A.1.2 Therapists

(1) Do you employ these tools in your practice?
    (a) If you use Brainwave-R, do you follow the protocol (e.g., the user is meant to rate how well they do before and after the exercises) or just provide the activity sheets to your patients?
(2) What other tools are you employing?
(3) How are you using these tools in your practice (e.g., for Brainwave-R, are they following the protocol/timeline given, or are they picking and choosing exercises for their patients)?

A.2 The Main Themes Identified in the PD Workshop with Associated Descriptions

The Main Themes Identified in the PD Workshop with Associated Descriptions

Cognitive activity engagement
*Games—This includes Sudoku, bridge, chess, and shape/block mobile applications.
Puzzles—Crosswords and jigsaw puzzles, for example.
Interaction mechanism—Older adults engage alone or with others (e.g., multiplayer online games), and either through pen and paper or using technology.
Motivational factors impacting cognitive activity engagement
Maintain cognition—Older adults engaged in cognitive activities to "keep the brain going," and therapists said the same about their patients.
Boredom—Engaging with cognitive activities to combat boredom.
Challenge themselves—This included challenging themselves indiviually and also against opponents.
Enjoyment—Engaging with cognitive activities that provide a high level of enjoyment.
Learning—Learning a language through Zoom classes or the Duolingo mobile phone application.
*Task Diversity—Incorporating variation in activities across sessions (e.g., for the Category Checker, one participant suggested different categories every day).
*Informality—Participants had a preference toward informal activities whereas the formal tasks can be "scary" and "boring."
Barriers to cognitive activity engagement
*Aspects of the technology—This includes pysical aspects such as screen/text size and other factors such as usability and trust.
Learning curve—Difficulty intrcting with new technologies and activities can inhibit cognitive activity engagement.
Physical and cognitive challenges—Physical challenges noted included sensory impairments (e.g., visual difficulties). Cognitive difficulties included memory, disorientation, comprehension, and organization/planning.
Engagement strategies for cognitive activities
*Encouragement—Many participants incorporated verbal encouragement into their designs, particularly in instances where they are having difficulty/performing poorly.
*Prompting—This includes auditory and visual prompts for high-level reminders to engage in cognitive activities as well as targeted prompts to assist older adults when encountering difficulty with a specific activity.
*Success—Framing all aspects of the interaction positively, such as through focusing feedback on improvements. Also, instead of highlighting incorrect answers with a cross ("X"), allow the user to try again or have the robot or sensory feedback guide them toward the correct answer.
*Rewards—Providing visual/auditory feedback at the end of an activity. Some examples included gold cup, fireworks, star, medal, personal picture, and music.
*Autonomy—Participants wanted to be granted control over certain aspects of the interactions such as in the Category Checker being able to choose the categories or for the feedback being able to choose their rewards.
*Fun and colorful—This is linked with informality, where participants wanted the interactions to be fun to engage with and incorporate colorful visuals.
*Video demonstration—Instead of written activity instructions, participants suggested providing them through video.
*Graphs and charts—Participants wanted their performance and feedback to be shown visually through graphs and charts.

Items marked with an asterisk and colored orange were further integrated into the prototype.

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