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Human Robot Engagement and Acceptability in Residential Aged Care

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Abstract.

People with dementia often suffer the limitation in their ability to communicate and express themselves clearly, consequently spend most of their time alone and are not engaged in social activity as before. The prolonged lack of engagement has contributed to a variety of negative health effects. The research on engagement and acceptability of people with dementia using assistive technology such as social robots can be useful to provide potential solution and sustainability. Thus, this paper focuses on the service design and the effectiveness of the engagement, and acceptability while interacting with a social robot named Matilda being trialled from 2010 till 2013 with 115 participants in Australian residential aged care facilities. Combining the most updated engagement assessment method and the robot acceptance model as the methodology, the findings of this study indicate there is a statistically significant improvement in emotional, visual and behavioural engagement of older people with social robots over the years. The post-trial survey has also verified their acceptance the interaction with social robots.

Keywords*:* social robot, engagement, acceptability, aged and dementia care.

Professor Rajiv Khosla has a multi-disciplinary background in management, engineering and computer science. His research in three disciplines, namely, Information Systems, Computing, and Engineering has been published and reported in journals like Pattern Recognition, Expert Systems with Applications, IEEE Transactions in Engineering Management, IEEE Multimedia, Communications of the ACM, and IEEE Transactions in Power Systems.

Dr Khanh Nguyen is currently a researcher at Research Centre for Computers, Communication and Social Innovation, La Trobe University. His research interests include designing social robot services for aged care and autism care, and machine learning, and big data analytics. His work has been published in journals such as Assistive Technologies, Journal of Information Science, World Wide Web Journal and other high quality conference proceedings.

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1. Introduction

The prevalence of dementia is growing rapidly with an estimate of 35.6 million people worldwide (World Health Organisation & Alzheimer's Disease International, 2012) and over 350,000 Australians live with dementia. (Alzheimer's Australia, 2016). People with dementia are found difficult to express themselves clearly and have much less engagement in social activities compared to what they used to have (Moyle, Kellett, Ballantyne, & Gracia, 2011; von Kutzleben, Schmid, Halek, Holle, & Bartholomeyczik, 2012). The prolonged lack of engagement may increase the risk of loneliness and social isolation (Cacioppo, Hughes, Waite, Hawkley, & Thisted, 2006; Moyle et al., 2011), cause decline in cognitive capacity (Zuidema, Koopmans, & Verhey, 2007) and possibly results in a high use of pharmaceutical interventions (Hwang, Kim, Yun da, Kim, & Jung, 2012).

Thus, improving the engagement of persons with dementia is important in dementia care, which in particular can reduce boredom and loneliness through an increase in positive connection (Materne, Luszcz, & Goodwin-Smith, 2014; van der Ploeg et al., 2013) and an improvement in quality of life (Gitlin et al., 2009). Researchers have been investigating the use of social robots as a means to engage, and stimulate social interaction with people with dementia (Kachouie, Sedighadeli, Khosla, & Chu, 2014) in order to address issues related to the looming health and aged care crisis. Thus, the effectiveness of engagement on people with dementia with social robot has attracted lots of attention recently.

On the other hand, the user acceptance towards technology has been an important topic in both industry and academic studies for several decades (Park & Kim, 2013). Particularly the innovative assistive technology such as social robot needs to examine the acceptance level from the user viewpoint to guarantee the success. The technology acceptance model (TAM) proposed by Davis (1989) has been extensively utilised for this purpose (Marangunić & Granić, 2015). For that reason, TAM is adopted in this study to measure the acceptability of older people in residential aged care to social robots to assess the deployment and sustainable use.

This paper uses Matilda as the specific social robot and studies its engagement and the acceptability of people with dementia in residential aged care facilities in Australia. Matilda was developed in joint collaboration between NEC Japan (a Japanese multinational provider of information technology services and products) and RECCSI (Research Centre for Computers, Communication and Social Innovation) of La Trobe University in Melbourne, Australia. It has rich human-like features with multiple communication modalities and was designed to deliver diversion therapy services to older people with dementia. The collected data (through video recordings and a post-trial questionnaire survey) of 8304 engagement reactions from 115 older residents in four different residential aged care facilities in Australia over four years (from 2010 to 2013) have been analysed for this study. Given the challenge of engagement analysis because of the reduced emotionality and cognitive ability in people with dementia (Jiska Cohen-Mansfield, Dakheel-Ali, Jensen, Marx, & Thein, 2012), the engagement measures of this research is drawn upon the most updated observational engagement assessment method proposed by Jones et al. (2015). Furthermore, the robot acceptability measures are constructed based upon the robot acceptance model developed by Heerink et al. (2010) and the original TAM model proposed by Davis (1989).

2. Related Work

2.1. Social robots for aged care

With the advancement of robotics research (Hiraki & Anzai, 2009) and human-robot interaction studies (Yilmazyildiz, Read, Belpeame, & Verhelst, 2016), robotics paradigm is shifting from an industrial technology to more consumer, home, and service oriented markets (Ma et al., 2014; Tung, 2016). Researchers have been investigating the use of robots to engage, and stimulate social interaction with people with disability (Fridin & Belokopytov, 2014). Pet-like robot like Paro, AIBO, NeCoRo and iCat have been trialled and reported having improvements in relaxation, socialization, and loneliness in older adults (Heerink, Kröse, Wielinga, & Evers, 2006; Kramer, Friedmann, & Bernstein, 2009; Tamura et al., 2004; Wada & Shibata, 2007). Although the preliminary success exists, these robots expose their limitations such as lack of human-like functionality involving human voice, gestures, emotion and other human attributes (Broadbent, Stafford, & MacDonald, 2009). In addition, they have limited range of communication modalities and diversion therapy services (Libin & Cohen-Mansfield, 2004; Toshiyo Tamura et al., 2004).

More recently, social robots with human-like features such Nao, Bandi, Kabochan Nodding Communication, Brian 2.1, Hobbit, Nexi, Pepper and PaPeRo have been introduced to support older people's emotional wellbeing (Khosla & Chu, 2013; Khosla, Nguyen, & Chu, 2016; Lammer, Huber, Weiss, & Vincze, 2014; Louie, McColl, & Nejat, 2014; McEvoy & Plant, 2014; Nunez, Matsuda, Hirokawa, & Suzuki, 2015; Shah, Wiken, Williams, & Breazeal, 2011). These social robots have been reported having positive impacts on different aspects of social engagement and emotional well-being of residents with dementia. For instance, research using Nao robots reported that these robots could improve communications among older people (Johnson et al., 2014). Another study (Lammer et al., 2014) found that Hobbit robot could improve older people's participations in daily activities. Brian 2.1 robot was reported that they had positive applications in social activities (Louie et al., 2014), on the other hand, Kabochan Nodding Communication robot had improvement of cognitive activities, especially in executive and memory functions (Tanaka et al., 2012). Studies by Khosla and his team reported that PaPeRo robot (named Matilda) succeeded in breaking technology barriers for older residents and had positive engagement in residential aged care (Khosla & Chu, 2013) and home-based care (Khosla et al., 2016). A more detailed literature survey can be found in a recent systematic survey article in relation to social robots (Kachouie et al., 2014).

2.2. Engagement of people with dementia

The concept of engagement has been documented in a range of settings (Cohen-Mansfield, Marx, & Werner, 1992; Conti, Amabile, & Pollak, 1995; Engelman, Altus, & Mathews, 1999). Engagement is defined as "the act of being occupied or involved with an external stimulus" (Cohen-Mansfield, Dakheel-Ali, & Marx, 2009). Engagement is important in people with dementia because it not only can help to reduce cognitive impairment in social activities but it is also associated with decreased restless behaviour, reduced use of psychotropic medications, improved nutrition, and increased family satisfaction in an adult day care centre (Volicer, Simard, Pupa, Medrek, & Riordan, 2006). Thus, the analysis of different forms of engagement of persons with dementia is expected to help such persons by reducing boredom and loneliness and by increasing interest and positive emotions. Cohen-Mansfield et al. (2012) reported that the analysis of engagement for person with dementia can also help determine person-centred activities to reduce boredom and loneliness, and thereby improve quality of life. However, lack of engagement was found being common among residents with dementia in residential care settings (Altus, Engelman, & Mathews, 2002). For that reason, in this study we focus on examining the engagement level of people with dementia to the new assistive technology like social robots.

Analysis of engagement is challenging for people with dementia as they have reduced emotionality (i.e., affective blunting), which makes the analysis of facial expression very challenging in this population (Cohen-Mansfield et al., 2012). The engagement assessment of people with dementia has been studied by Cruz et al. (2013) focusing on the frequency and duration of the behavioural aspect of engagement. On the other hand, Kolanowski et al. (2011)

measured the time spent by a person with dementia on participating in an activity and the intensity of their participation together with a modified version of Nolan et al.'s (1995) molar coding scheme. Given the limited measures of engagement of people with dementia in these studies, and the challenges of video recordings with variations in coding, a new approach to assess engagement in people with dementia has been recently developed by Jones et al. (2015). The engagement measures in this article are thus drawn upon from this approach.

2.3. Technology Acceptance Study

The technology acceptance model (TAM) (Davis, 1989) has been extensively and successfully utilised to explain the processes by users if they accept or reject new technology. Similarly, for social robots to be successfully adopted in aged care, they need to be accepted by older people. Thus, measuring the acceptability of older people towards Matilda is important. To evaluate the acceptance of older residents with social robots, in this study we construct the acceptance measures using the robot acceptance model developed by Heerink et al. (2010) which is based on the TAM proposed by Davis (1989) .

3. Theoretical Underpinnings of Service Design for Engagement and Acceptability

3.1. Matilda's specifications

Matilda is the robot deployed during field trials in this research is designed in collaboration between RECCSI researchers and NEC Japan. Its specifications are shown in Figure 1. Matilda's human attributes include baby-face-like appearance, human voices, facial expressions, gestures, and body movements. It has capacity of recognising voices, human faces, emotion detection and speech acoustics recognition.

3.2. Theoretical Underpinnings of Service Design

Several research has indicated that negative consequences of ageing and dementia can be mitigated by designing an approach towards care that respects and supports each individual's personhood (Cohen-Mansfield, Parpura-Gill, & Golander, 2006; Tinney et al., 2007; O'Connor et al., 2007). Personhood is defined as "the standing or status that is bestowed upon one human being, by others, in the context of relationship and social being" (Flicker, 1999), including three fundamental components, namely, interactional environment, subjective experience and social context. To facilitate the engagement and acceptability, Matilda's services are designed around the major components of personhood used by people with dementia.

In the aged care context, the subject experience can be linked to emotional well-being including five elements defined by Department of Health (2010) in Victoria, Australia. Based on the discussions with care givers, dementia care service providers, and interactions with several people with dementia in residential aged care, the services to each construct have been designed. The mapping between the constructs of emotional wellbeing and Matilda's services is shown in Figure 2. By marrying each service with communication modalities like voice, emotive expressions (e.g., blushing), head and body movements in different range, and intensity depending on service context (e.g., lyrics of the song, story expression), Matilda facilitates positive emotional reactions (e.g., responding with positive expressions and actions such as kissing the robot) and reciprocity (e.g., calling robot's name, or responding to its instructions during the games and other activates).

3.3. Matilda's Services

Bingo & Hoy games

The Bingo and Hoy games were designed following the recommendation by the staff of aged care facilities where the trials were conducted. Those aged care facilities played Bingo game as group therapy for their residents. Matilda was programmed to call out numbers (for Bingo game) or cards (for Hoy game) and at the same time project the numbers/cards to a screen (Figure 3), to support older people with visual or hearing impairment. The touch interface was used to control the calling the next number, so that the residents could play the games at their own paces. During the trials, the visual display of the called numbers was improved from displaying all called numbers to only displaying a current calling number in very big number size to better support the visual impairment conditions of some residents.

Music and dancing

Matilda can play music and dance. Several dancing patterns were designed by combining head motion and body motion to give Matilda the capacity of performing different dancing patterns. We integrated the genre and lyrics of the songs with the dancing patterns. Initially in 2010 this integration was arbitrary but in subsequent years we made the interface of robot appear more natural to the participants in terms of head and body movement matching with the genre of the song (e.g. rock n' roll song was modelled with faster body movement, conversely, classical song was modelled with slower head body movements). Similarly, the cheek and mouth expressions and colours of the robot were adapted to the genre and lyrics. New music albums or files could be uploaded to Matilda at any time.

Quiz and Storytelling

Text and photo-based quizzes could be written and uploaded to Matilda with a friendly use of touch panel interface. The resident could answer the quiz question vocalized (and visual displayed on touch panel, smart TV or projector) by using their voice or touch interface. Similarly, short stories (text or audio) could be uploaded to Matilda.

Reminder, Weather and Others

Matilda could remind people with dementia about the daily schedule, tell them weather, news, date and time. The robot is also capable of making phone calls using Skype through an internet connection.

3.4. Human-like Attributes

In order to deliver such rich human-like features, Matilda was designed to be able to automatically extract the emotion from text input and perform according to emotive expressions (Figure 4) and gestures (i.e., head and body movement). The demonstration of Matilda's emotive expressions is shown in figure 5.

Let s be a text input and w_s an emotion label. Let e be a set of m possible emotion categories (excluding neutral) where $e = \{e_1, e_2, \ldots, e_m\}$. The objective is to label s with the best possible emotion label w_s , where $w_s \in \{e_1, e_2, \ldots, e_m, neutral\}$.

First, the semantic model is trained with BNC[1] (British National Corpus) using Latent Semantic Analysis (LSA) (Hofmann, 1999) to create the semantic vector space. Then, we extract six synonym sets of affective words corresponding with six emotions (anger, disgust, fear, joy, sadness, and surprise) from WordNet-Affect (Carlo Strapparava & Valitutti, 2004). The effect synsets are then being folded into the semantic space using the folding-in technique (Deerwester,

[1] BNC is a 100 million word collection of samples of written and spoken language from a wide range of sources (http://www.natcorp.ox.ac.uk/)

Dumais, Furnas, Landauer, & Harshman, 1990) to form effective anchor vectors which represent six emotion categories in the semantic space.

Given text input needs to identify its emotion, it can be represented by a vector in the LSA space formed by summing up the normalized LSA vectors of all the terms contained in it. Finally, the affect of the text input can be identified by computing the cosine similarity measure among the input vector and the affective anchor vectors. If similarity is defined between a given input text s, and an emotional class, e_j as $sim(s,e_j)$, the affect w_s of s are formally represented as follows:

$$w_s = \begin{cases} \arg\max\left(sim(s,e_j)\right) & if\; sim(s,e_j) \geq t \\ neutral & otherwise \end{cases}$$

Where $sim(s,e_j)$ is computed as cosine between the vector v_s of s and the affective anchor vector v_{e_j} of emotional class e_j:

$$sim(s,e_j) = \frac{v_s \cdot v_{e_j}}{\|v_s\| \cdot \|v_{e_j}\|}$$

3.5. Multi-modal Interaction

Low care and high care residents in residential care facilities have different kinds of mental and physical limitations which require different types of interactions. Matilda has been designed to communicate in speech mode, touch panel mode and facial recognition mode (Figure 6). The various modes of communication facilitate Matilda the ability of engaging residents with different medical conditions (e.g., deafness, dementia, short term memory loss).

The touch interface is designed for touch-screen panels (tablets). Due to the dementia symptoms of the human partner, these touches interface uses big touch buttons combining text and visual cues. For speech recognition, built-in microphone and/or a Bluetooth wireless microphone can be used. The advantage of the Bluetooth wireless microphone is that a human partner can give voice commands meters away from the robot. This is convenient for a large group therapy services in which some participants may sit far from the robot, or for caring staff to communicate with the robot.

4. Research Method

This research was designed to study the engagement and the acceptability of people with dementia to social robot Matilda in residential aged care facilities in Australia.

4.1. Setting

The trials of this research were conducted in four residential aged care facilities in Australia from 2010 till 2013. The snapshots of the trials are shown in Figure 7.

4.2. Participants

A total of 115 persons with dementia aged 65-90 years participated in the trials. The participants had mild to advanced dementia. These participants also had multiple medical conditions and even limited mobility. The statistics of participants are shown in Table 1.

4.3. Outcome measures

The engagement measures of this research were adopted from the engagement analysis proposed by Jones et al. (2015), while robot acceptability measures were constructed based on the technology acceptance model developed by Heerink et al. (2010). The outcome measures are shown in Table 2. The measures of engagement were coded based on the guideline for video coding of engagement proposed by Jones et al. (2015).

The engagement of the participants in terms of their interaction with the robot was measured for three services delivered by the robot, namely, singing and dancing, playing games like Bingo (play with numbers) and Hoy (play with cards) and general knowledge quiz.

Emotional engagement in people with dementia was assessed via facial emotional responses based upon a modified version of the observed emotional rating scales of Lawton et al. (1999). The participant's emotional response (i.e., facial expressions) to the robot was coded as either neutral, pleasure, anger, anxiety/fear, or sadness. The elements of the scale were simplified to allow for the blunted affect of a person with dementia, thus focusing on the three clearly emotional responses (i.e., pleasure, neutral and negative affects) where by negative affect consists of anger, anxiety or fear, and sadness.

Visual engagement is an important indicator of non-verbal engagement (Cohen-Mansfield et al., 2009; Lawton et al., 1999). In our coding scheme, we examined the presence of visual engagement (i.e., visual alertness and eye gaze) and the lack of visual engagement.

Behavioural engagement was modified from the work of Cohen-Mansfield et al. (2009) and Kolanowski et al. (2011). Observations of positive behavioural engagement in this research included clapping hands, dancing with the robot, touching or attempting to touch the robot as well as stroking, petting, nuzzling, and holding the robot.

Drawing from the work from Clair (2002), verbal engagement was assessed as the times the persons with dementia participating in a conversation with the robot, singing along with the robot or talking with others about the robot. The absence of these signs was coded as not verbally engaged.

Robot acceptability was defined and assessed through attitude towards robots, perceived usefulness, perceived enjoyment, perceived sociability and anxiety which participants experienced during the trial and it was conducted using post-trial survey. The questionnaires were designed and administered to the participants to elicit their feedback on the field trials of Matilda with the assistance of a director of nursing and several nursing home managers who all had many years of experience in the aged care industry. Being mindful of the possible frail health of participants, the questions were designed to be short and simple. The participants' perceptions and reactions to the social robot were recorded using a standard five-point Likert scale (Strongly Disagree=1, Disagree=2, Neutral=3, Agree=4, Strongly Agree=5).

Seventy residents in three residential care facilities were invited to complete the survey. Thirty-four residents from three residential care facilities (nursing homes) in the Australian states of Queensland and Victoria participated in a questionnaire survey. Of the 43 respondents, 34 (79%) are female and only 9 (21%) are male. Both low care and high care residents were involved in the trial. Hence, some of the residents involved also suffered from various medical conditions, including depression, dementia, Parkinson disease, deafness, and short-term memory loss etc.

4.4. Procedure

Each trial involved three different stages. Firstly, Matilda was introduced to the participants by briefing them on how it interacted and entertained participants. It included a short demonstration of Matida' services. The second stage involved the interaction between residents with Matilda through singing (multilingual) songs, playing quiz or storytelling activities. The participants interacted with Matilda through different communication modalities such as touch control or voice commands. Finally, robots played several bingo games with the older residents by calling the numbers and projecting the numbers on the big screen as shown in Figure 3. For each game, there was one participant who was using the touch interface to control the calling of next number, so that the residents could play the games at their own pace.

Every trial took 4-6 hours and might repeat more than one time with the same participants. By analysing data from videos recorded using camcorder, a total number of 8304 engagement reactions were observed to assess the engagement of the participants. After each trial, the diversion therapy services provided by Matilda were improved based upon the feedback from nursing staff or older residents in terms of satisfaction. For example, the people with dementia requested the improvement from American accent to Australian accent while playing bingo with the robot. Another example is the visibility of the numbers displayed on the screen by the robot were enhanced significantly in terms of size, and the speed of calling numbers was determined by the participants who used a touch panel to command the robot to call the next Bingo number.

4.5. Video coding protocols

A video coding protocol was used to analyse participants' emotional engagement, visual engagement, behavioural engagement and verbal engagement during the intervention sessions. The coding protocol was based on the assessment of engagement from video analysis developed by Jones et al. (2015). The coding protocol was used to code each individual participant's engagement with robot at the time it occurred on the video. The two coders individually coded each recording. Inter-rater reliability of the video analyses between the two coders was computed, with a high inter-rater reliability of 89.9%.

5. Results

SPSS 23.0 was used for data entry and statistical computation. We performed one multivariate analysis of variances (MANOVA) with all the engagement measures as dependent variables, and year and genders as independent variables to determine an overall effect. We found that that there was an overall effect of year on engagement (F (15, 1869) = 4.23, $p < .0001$; Wilk's $\Lambda = 0.91$, partial $\eta2 = .30$). We did not find any gender main effect or year x gender interaction. For that reason, to determine how the engagement measures differ for the main effect, we conducted tests of between-subjects effect. The results revealed that there were statistically significant differences in the means of pleasure (F (3, 681) = 3.33; $p = .019$; partial $\eta2 = .014$) visual engagement (F (3, 681) = 16.04; $p < .0005$; partial $\eta2 = .066$) and behavioural engagement (F (3, 681) = 3.68; $p = .012$; partial $\eta2 = .016$) between the years. Thus, the results of ANOVAs were reported.

5.1. Emotional Engagement

The output of the ANOVA analysis found that there was a statistically significant difference in the means of emotional engagement between the years (F (3, 681) = 3.33; p = .019; partial η^2 = .014). The estimated marginal means of pleasure in each year in Table 3 indicate that there is an increase of positive emotion reactions in subsequent years compared to the baseline 2010. The comparisons of mean difference between the years in Table 4 show that there is a significant increase of positive emotional engagement in 2013 compared to the baseline year 2010 (p = 0.03). The follow-up linear trend analysis finds that the F-ratio is 12.84 and this value is significant at .001 level.

Conversely, the negative emotion responses of the participants across the years are shown in Table 5, indicating very low negative emotion reactions of the participant to the social robot. However, there was no statistically significant difference of this measure between the years (F (3, 681) = .33; p = .804 > .05; partial η^2 = .001). From the data entries of this measure we found that most of the negative emotion expressions were anxiety related to the first contact with the social robot or the sadness (including the unhappiness of not winning the group Bingo or Hoy or not correctly responding to quiz) while the angry expressions rarely occured during the trials.

5.2. Visual Engagement

There was a statistically significant difference in visual engagement between the years determined by the output of ANOVA (F (3, 681) = 16.04; p < .0005; partial η2 = .066). The estimated marginal means of visual engagement across the years in Table 6 show the high visual engagement of the participants to the social robot. There is an upward trend with a sharp increase from 2011 compared with the baseline year. The comparisons of visual engagement across the years in Table 7 reveal that there is statistically significant improvement in visual engagement in subsequent years 2011, 2012, and 2013 compared to the baseline year 2010 (all p values < .001).

5.3. Behavioural Enagement

Statistically, there was a significant difference in behavioural engagement between the years (F (3, 681) = 3.68; p = .012; partial η^2 = .016). For that reason, a post-hoc test was performed to determine which groups of years were statistically significant differences. Behavioural engagement estimated marginal means in Table 8 show that the means are in an anticipated direction from 2010 to 2013. The mean differences in Table 9 illustrate that the mean in the baseline year 2010 is significantly lower than the means in years 2012 and 2013. However, the table indicates that there are no statistically significant differences in the means between other years.

5.4. Verbal Engagement

Table 10 shows the estimated marginal means of verbal engagement across the years. It demonstrates that there are slightly improvements in 2011, 2012 and 2013 compared to the starting year 2010 but these differences are not statistically significant, determined by the ANOVA's output (F (3, 681) = 0.364; p = .78; partial η2 = .016). Thus, a post-hoc test was not followed up for this measure. It may be noted that the verbal engagement in the trials was mostly relevant during singing and dancing sessions. In activities like playing Bingo and Hoy verbal engagement was minimal because the participants played the game seriously and verbal engagement during the game was considered disruptive. However, after the game some verbal engagement was observed in terms of social interaction (e.g., participants comparing notes).

5.5. Robot Acceptability

SPSS analytics software was used for analysing the survey data. A reliability analysis was used to test the internal consistency of the instrument resulted to a Cronbach's alpha of 0.874. The descriptive statistics based on the survey of the residents conducted after the field trials are shown in Table 11.

In general, the participants expressed a very positive attitude towards the social robots. In specific, 89% of respondents agreed or strongly agreed they feel comfortable with Matilda dancing and blushing and only 2% disagreed with that. 75% of the survey participants felt relaxed talking with Matilda, while 16% of them disagreed. In addition, 61% of respondents also had positive attitude towards the way the robot responded to them. Most of residents who disagreed on this mostly concerned on the speed of voice vocaliser. The speed of Matilda's reactions during game playing was then adjusted to suit their cognitive conditions.

In term of perceived usefulness, 60% of respondents positively responded Matilda could improve their daily life, while the rest of the respondents were not sure about this, but almost of them (86%) agreed Matilda made them feel better.

The residents responded very positively to the perceived enjoyment questions, with 84% of respondents enjoyed the contact with Matilda and only 7% of them did not enjoy that.

In term of perceived sociability, high number of participants responded they liked to participate in group activity with Matilda (60%) or wanted Matilda to be their friend (63%) but they were quite neutral when responding to the question if Matilda helped them make more friends. In residential aged care context, this can be explainable since most of residents may already meet or know each other. 84% of respondents did not feel concerned about the present of Matilda and only 4% expressed concerns about its presence.

6. Discussion and Implications

This section provides a discussion on outcomes of engagement and acceptability of the social robots in residential care facilities in Australia in terms of service context, robot interface context, participants' context and the implications of our work.

6.1. Engagement

Emotional Engagement

Under the service context, singing and dancing provide sensory enrichment to the participants. During the time period of 2010 to 2013 we integrate a rich range of songs and music involving different genre and artists to personalize the sensory experience to each participant. This helps us over the years to improve the positive emotional engagement between the robot and the participants.

In the robot interface context, Matilda has been programmed to integrate the genre and lyrics of the songs with the human-like emotive expressions, head and body movement of the robot. The integration of arbitrary dancing performance in the baseline year has been replaced by more natural and meaningful dancing patterns in terms of head speed and body movement matching with the genre of the songs in the subsequent years.

From the participants' context, the participants in our trials have mild to advanced dementia. By carefully personalizing the songs and music overtime we are able to augment their good memories and positively engage them with robot singing and dancing to their favourite songs.

By taking considerations of these contexts in service design and improvement in music personalization, dancing interface to augment the positive memories linked with their favourite songs helps us to improve the emotional engagement of the participants over the trials.

Visual engagement

From the service context view, the people with dementia have memory impairment, thus the numbers and cards displayed on the screen needed to remain there after they are called by the robot. We have gradually improved the layout of this display in terms of the size of the numbers or cards displayed and positioning of the numbers and cards on the screen to improve the visual engagement of the participants while playing the game.

In the context of the robot and other communication device, the visual engagement is incrementally improved by using graphic symbols with real life metaphors for choosing different services by people with dementia who may lose their word vocabulary overtime. Additionally, for playing games like Bingo and Hoy the touch panel layout is enhanced with play options more visually pleasing and easier to see for giving commands to the robot. The baby face of the robot also facilitates the visual engagement with the participants.

From participants' context, several participants in our trial have hearing and visual impairment. Thus in order to improve their visual engagement Matilda has to call and display the bingo numbers on the screen at the same time. The above improvements in design of services, interface and factoring participants' disabilities help us to improve the visual engagement.

Behavioural engagement

From the service context viewpoint, a rich range of songs and music of different genres and artists ranging from pop, classical, rock and roll, and so on is integrated over the years to provide the social robot a better capacity of personalising the music choice of the participants. Thus, Matilda is able to play favourite tunes to the residents which encourage the behavioural engagement such as clapping hands. Additionally, playing and winning game and quiz activities with Matilda provides the participants a sense of achievement and satisfaction which also contributes to positive behavioural engagement.

In the robot interface context, we have integrated the genre and lyrics of the songs with the several designed dancing patterns of the robots which combines head and body movement with emotive expressions of the robot. The dancing of the robot together with playing their favourite tunes contributes to positive behavioural engagement.

Verbal engagement

From the service context, personalising the songs to augment good memories results in some participants singing along with the songs played and danced by the robot. In the diversion therapy game like Bingo and Hoy, the verbal reactions also occur at the end of each game as someone wins the game. However, the verbal engagement less occurs during game plays, since it could distract the hearing and looking of the calling number/card of other participants.

6.2. Acceptability

The positive engagement of Matilda to the participants contributes to its acceptance amongst the participants. The acceptability is also facilitated by accounting for various disabilities of participants in the design of Bingo and Hoy games. The participants suffer from various disabilities including hearing and visual impairment, dementia (cognitive impairment), depression, etc. Matilda uses voicing and visually displaying the cards as well as relinquishing control to the elderly (in terms of the pace at which the cards are called by allowing elderly to use the touch panel for sending the control commands) helps to improve effectiveness of elderly with various disabilities to play the game successfully. Prior to introduction of Matilda, only one care giver is employed for calling the cards thus limiting the effectiveness in terms of elderly with visual and cognitive impairments.

In addition, the use of Matilda's gestures (nod) and music accompanied by dance movements (after someone wins the game) is welcome by the elderly and improves its acceptability and social interaction.

Finally, the physical embodiment of baby like face, human-like multimodal attributes facilitates natural interaction with the elderly who seem to forget they are actually interacting with technological device.

6.3. Implications

This research demonstrates that robot-enabled human-centred system like Matilda with human-like characteristics involving voice, gestures and emotive expression has potentially engaged people with dementia and broken the technology barriers. In terms of practical implications, the work indicates that social robots like Matilda may be used in aged and dementia care as a supplement to engage older residents in meaningfully social activities and group therapy services like Bingo games, singing and dancing, and so on. Matilda is non-judgemental and the participants do not complain any problem while interacting with it.

There are two theoretical implications of this research. Firstly, socially robots need to be designed in a social context. Within the social context the robot enabled services for the human partner need to be underpinned in concept of personhood to enable personalization of services and its contents to suit the preferences (i.e., favourite songs, stories, games) and health conditions (visual and hearing impairments) of older residents. The arrangement of care-giving in Asian, African and European societies has long been based on principle of personhood (Van der Geest, 2002; Van der Geest, Mul, & Vermeulen, 2004). We have applied this principle in residential care facilities and designed activities in Matilda relevant to social context in residential care facilities in Australia. By designing Matilda to play games with residents (a popular group diversion therapy activity), sing and dance their favourite songs which augments their good memories, we are able to facilitate acceptability of Matilda among residents. Besides being a means of social engagement, playing and winning games has therapeutic affect and makes older persons become social and useful. In addition, for robot service designers, service context, robot interface context, participants' context should be carefully considered and embedded in the design to make the human-robot interface to become believable for breaking technology barrier and facilitate a long term meaningful reciprocal relationship between social robot and people with dementia. This aspect has clear implications for design of interactional environment and communication modalities, and ornamental design of the robot to enable its productive use.

7. Conclusions

This paper aims to study the engagement and acceptability of people with dementia with social robot (Matilda) through designing, implementing and trialling robot-enabled diversion therapy services in several residential aged care facilities over a four-year period from 2010 to 2013. Due to the challenge of engagement assessment caused by the dementia symptoms of the participants, several engagement measures have been drawn based upon the engagement assessment models developed by Jones et al. (2015). The acceptability has been assessed based on the technology acceptance model developed by Heerink et al. (2010).

The analysis of engagement in this study shows the participants have positive engagement with Matilda There are statistically significant improvements in emotional engagement, visual engagement and behavioural engagement in successive years compared to the baseline year. The acceptability analysis shows that the participants have very positive attitudes towards Matilda.

Most of the participants have high ratings to the perceived usefulness and enjoyment of their experience with the robot. Remarkably, only 2% feel concerned with the presence of Matilda. The results implicate that by socially engaging older persons with meaningful activities provided and medicated by Matilda, we are able to break technology barriers and encourage acceptance of Matilda amongst the older residents.

Videos demonstrate the engagement of older persons with Matilda can be watched in the following links:

http://www.youtube.com/watch?v=ai1oqYXKrrY&feature=youtu.be

http://www.latrobe.edu.au/reccsi/media-releases/robots-in-aged-care

https://www.youtube.com/watch?v=cAS_ygqO5dA

http://www.latrobe.edu.au/reccsi/media-releases/field-trialhttps://www.youtube.com/watch?v=xX0-Ggt-Xz0&feature=youtu.behttps://www.youtube.com/watch?v=pBmFc-JSTL0&feature=youtu.be

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Figure 1. Matilda specifications and real prototypes

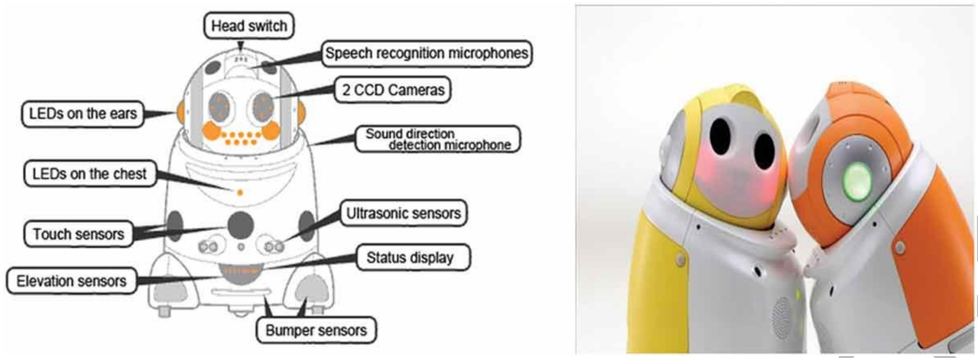

Figure 2. Matilda's design to facilitate engagement and acceptability.

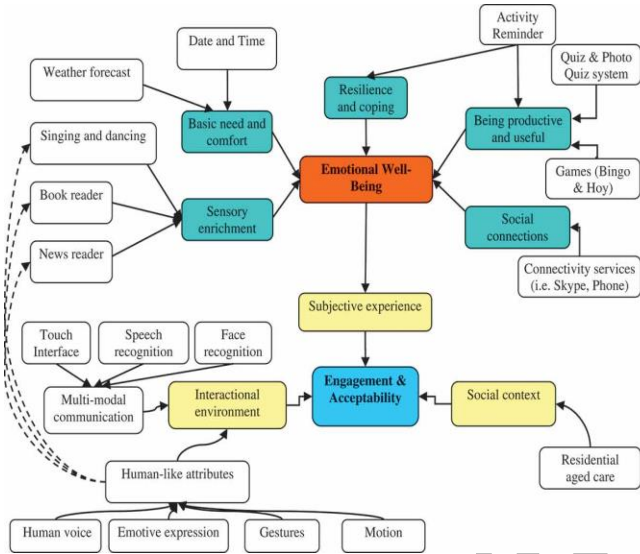

Figure 3. Matilda is playing games (Bingo and Hoy) with people with dementia and projecting the calling numbers/cards to the screen.

Figure 4. Delivery of human-like functionality evolving voice, emotive expression (emotion, gesture), and sound effect mediated by intelligent text emotion extraction.

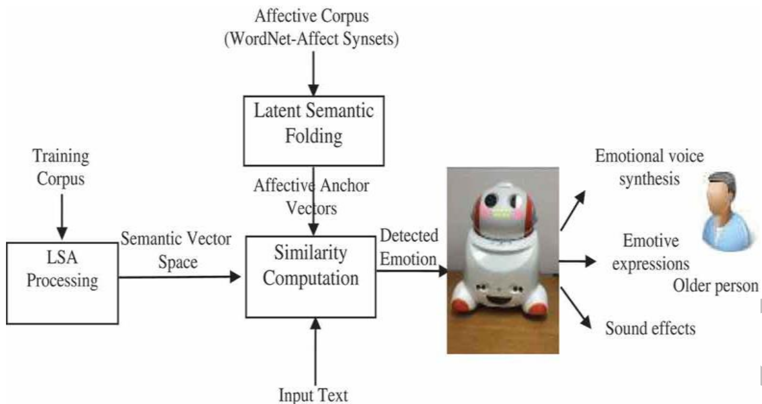

Figure 5. The robot expresses sad emotion (left) and happy emotion (right).

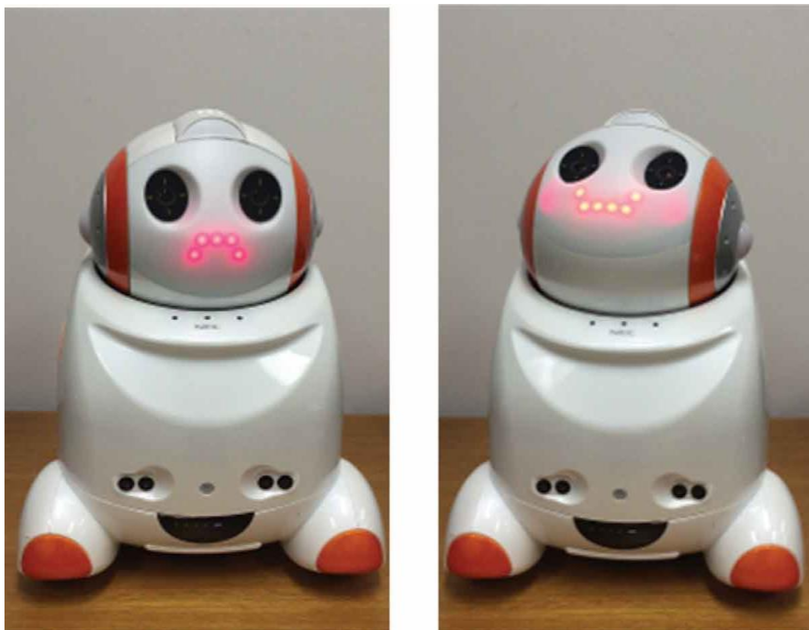

Figure 6. One of visual touch interfaces of Matilda (left), wireless microphone (right) used for speech recognition.

Figure 7. The participants are interacting with social robot during the trials

Table 1. Statistics of participants

Year	Residents with dementia		
	Female	Male	Total
2010	14	11	25
2011	31	3	34
2012	6	4	10
2013	29	17	46
Total	80	35	115

Table 2. Outcome measures

Measure		Observation
Emotional Engagement		
	Pleasure	Smiling, laughing to robot.
	Negative (Anger, Anxiety or fear, Sadness)	Physical aggression, yelling, cursing, drawing eyebrows together, clenching teeth, pursing lips, narrowing eyes. Crying, frowning, eyes drooped, moaning, sighing, eyes/head turned down. Voice shaking, shrieking, repetitive calling out, line between eyebrows, lines across forehead, tight facial muscles.
	Neutral	No sign of discrete facial expression.
Visual engagement		

	Positive visual engagement	Appears alert and maintaining eye contact with robot and other communication devices enabled by the robot (e.g., white display screen for Bingo and Hoy, touch panel screen used to give commands to the robot by the participant) Eyes following robot or looking at robot.
	No visual engagement	Appears inattentive. Blank stare into space. Does not make eye contact with robot.
Behavioural engagement		
	Positive behavioural engagement	Clapping hands, dancing with the robot. Touching or attempting to touch robot. Stroking, petting, nuzzling, and holding robot.
	No behavioural engagement	No touching; no physical contact with robot.
Verbal engagement		

	Positive verbal engagement with robot	Singing along with the robot. Participating and maintaining conversation, verbally responding to robot and about robot. Maintaining conversation with robot or about robot.
	No verbal engagement	Not participating and maintaining conversation.
Robot Acceptability		**Questionnaire**
	Attitude towards robots	Are you comfortable with Matilda? Do you feel relaxed talking to Matilda? Do you like the way Matilda respond to you?
	Perceived usefulness	Do you think Matilda can improve your daily life? Did Matilda make you feel better (e.g. make you smile)?
	Perceived enjoyment	Do you enjoy the contact with Matilda? Do you enjoy one to one activity (e.g., quiz) with Matilda?

	Perceived sociability	Do you like Matilda to be your friend? Do you like to participate in group activity (e.g. beano, hoy) with Matilda? - Do you think Matilda can help you to make more friends?
	Anxiety	- Do you feel concerned the presence of Matilda?

Table 3. Estimated marginal means of pleasure

Year	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
2010	.138	.043	.053	.222
2011	.170	.051	.069	.271
2012	.222	.039	.146	.298
2013	.285	.026	.233	.336

Table 4. Pleasure comparisons across 2010 - 2013

(I) Year	(J) Year	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2010	2011	-.04	.053	.872	-.18	.10
	2012	-.09	.053	.370	-.22	.05
	2013	-.15*	.044	.003	-.27	-.04
2011	2010	.04	.053	.872	-.10	.18
	2012	-.05	.054	.831	-.18	.09
	2013	-.11	.045	.053	-.23	.00
2012	2010	.09	.053	.370	-.05	.22
	2011	.05	.054	.831	-.09	.18

	2013	-.07	.045	.424	-.18	.05
2013	2010	<u>.15*</u>	.044	<u>.003</u>	.04	.27
	2011	.11	.045	.053	.00	.23
	2012	.07	.045	.424	-.05	.18
The error term is Mean Square (Error) = .178. *. The mean difference is significant at the .05 level.						

Table 5. Estimated marginal means of negative emotion

Year	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
2010	.087	.026	.036	.137
2011	.079	.030	.021	.138
2012	.075	.023	.029	.121
2013	.060	.016	.029	.091

Table 6. Estimated marginal means of visual engagement

Year	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
2010	.173	.049	.077	.269
2011	.421	.083	.258	.584
2012	.509	.044	.422	.596
2013	.564	.030	.506	.623

Table 7. Visual engagement comparisons across 2010-2013

(I) Year	(J) Year	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2010	2011	-.31*	.060	.000	-.47	-.16
	2012	-.33*	.060	.000	-.49	-.18
	2013	-.39*	.050	.000	-.52	-.26
2011	2010	.31*	.060	.000	.16	.47
	2012	-.02	.061	.987	-.18	.14
	2013	-.07	.051	.458	-.21	.06
2012	2010	.33*	.060	.000	.18	.49
	2011	.02	.061	.987	-.14	.18

	2013	-.05	.051	.716	-.19	.08
2013	2010	.39*	.050	.000	.26	.52
	2011	.07	.051	.458	-.06	.21
	2012	.05	.051	.716	-.08	.19

The error term is Mean Square (Error) = .230.

*. The mean difference is significant at the .05 level.

Table 8. Estimated marginal means of behavioural engagement

Year	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
2010	.117	.043	.032	.202
2011	.185	.050	.087	.283
2012	.263	.039	.186	.340
2013	.271	.026	.220	.323

Table 9. Behavioural engagement comparisons across 2010-2013

(I) Year	(J) Year	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2010	2011	-.09	.053	.354	-.22	.05
	2012	-.14*	.053	.040	-.28	.00
	2013	-.16*	.044	.002	-.27	-.05
2011	2010	.09	.053	.354	-.05	.22
	2012	-.05	.054	.745	-.19	.08
	2013	-.07	.045	.373	-.19	.04
2012	2010	.14*	.053	.040	.00	.28

	2011	.05	.054	.745	-.08	.19
	2013	-.02	.045	.979	-.13	.10
2013	2010	.16*	.044	.002	.05	.27
	2011	.07	.045	.373	-.04	.19
	2012	.02	.045	.979	-.10	.13

The error term is Mean Square (Error) = .180.

*. The mean difference is significant at the .05 level.

Table 10. Estimated marginal means of verbal engagement

Year	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
2010	.066	.030	.008	.125
2011	.094	.034	.026	.162
2012	.101	.027	.047	.154
2013	.101	.018	.066	.137

Table 11. Descriptive statistics of robot acceptability

Robot Acceptability	Strongly agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly disagree (1)
Attitude towards robot					
Are you comfortable with Matilda (e.g. dancing, blushing)?	56%	33%	9%	0%	2%
Do you feel relaxed talking to Matilda?	40%	35%	9%	7%	9%
Do you like the way Matilda respond to you?	28%	33%	23%	2%	14%
Perceived usefulness					
Did Matilda make you feel better (e.g. make you smile)?	44%	42%	7%	2%	5%

Do you think Matilda can improve your daily life?	23%	37%	21%	14%	5%
Perceived enjoyment					
Do you enjoy the contact with Matilda?	51%	33%	9%	5%	2%
Do you enjoy one to one activity (e.g., quiz, reminder) with Matilda?	30%	19%	33%	2%	16%
Perceived sociability					
Do you think Matilda can help you to make more friends?	33%	30%	12%	9%	16%
Do you like to participate in group activity (e.g. bingo, hoy) with Matilda?	23%	37%	19%	7%	14%
Do you like Matilda to be your friend?	33%	30%	12%	9%	16%

Do you like to touch Matilda?	7%	23%	40%	14%	16%
Anxiety					
Do you feel concerned in the presence of Matilda?	2%	2%	12%	19%	65%