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ORIGINAL RESEARCH

Bibo the Moving Cup for People Affected by Dementia: Design, Ethical Considerations, and First Observations in Use

Avgi Kollakidou[1] · Kevin Lefeuvre[2] · Christian Sønderskov Zarp-Falden[1] · Elodie Malbois[1] · Leon Bodenhagen[1] · Norbert Krüger[1,3] · Eva Hornecker[2]

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Abstract

We present the concept and technical realisation for a cup that moves and lights up to bring itself to the attention of a person to trigger him/her taking a sip as a response. We then reflect on different ethical dimensions connected to the application of the cup in the context of people affected by dementia and describe first tests performed in elderly care homes. The concept is aimed at people with dementia in home or resident care who still have the ability to act, but tend to mentally drift away and thus require external impulses and triggers to drink. We found out that a substantial part of the residents fulfil these conditions. The cup moves and lights up in regular intervals if it has not been picked up recently. Once it is emptied, it alerts a caregiver to refill. Moreover, the degree or level of movement and light can be configured, depending on the person's needs and reactions. This paper describes the core idea and the technical aspects of building the prototype. Finally, primary tests were conducted with the aim to construct a protocol and structure for an extended quantitative study.

Keywords Dementia · Dehydration · Elderly care · Robot ethics

Introduction

A general concern in the support of people affected by dementia in long-term care is to prevent dehydration [1, 2]. These people often do not perceive being thirsty and therefore do not drink enough. In previous fieldwork in different elderly care homes in Germany and Denmark, it was observed that often a resident would take a sip, put down the cup, and then stare into space again, until a staff member would move the cup towards their hand. Often, the resident then looked at and took the cup up again to drink. This external trigger brought the cup to resident's awareness again; however, such regular motivation of residents poses a significant workload to staff.

This observation motivated the concept of a moving cup which brings itself to attention (as illustrated in Fig. 1) without human stimulation by care staff. The concept goes beyond existing products (discussed in more detail in "State

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✉ Avgi Kollakidou
avko@mmmi.sdu.dk

Kevin Lefeuvre
kevin.lefeuvre@uni-weimar.de

Christian Sønderskov Zarp-Falden
csz@mmmi.sdu.dk

Elodie Malbois
elmal@mmmi.sdu.dk

Leon Bodenhagen
lebo@mmmi.sdu.dk

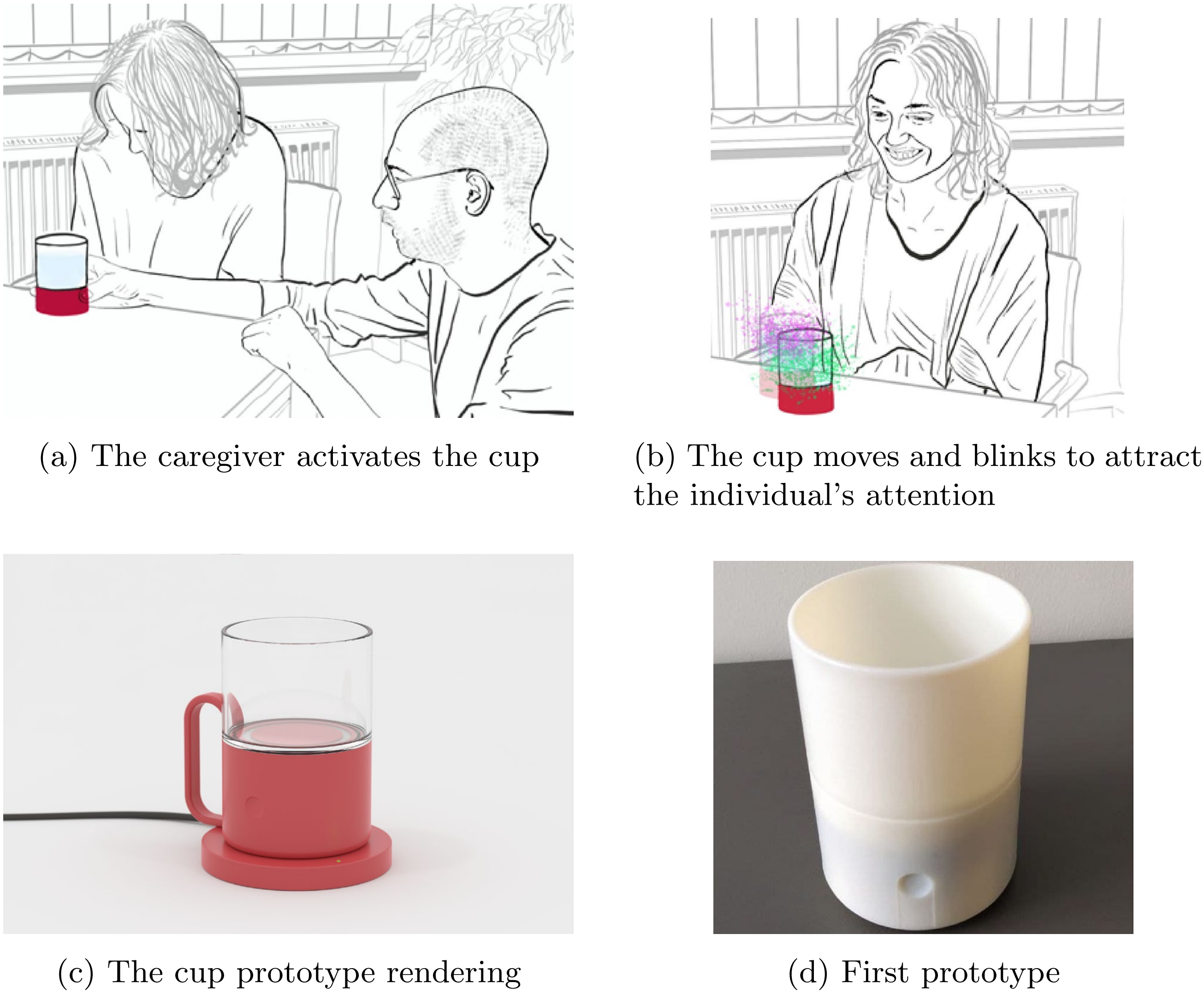
Norbert Krüger
norbert@mmmi.sdu.dk

Eva Hornecker
eva.hornecker@uni-weimar.de

1 SDU Robotics, Mærsk Mckinney Møller Institute, University of Southern Denmark, Campusvej 55, 5230 Odense, Denmark

2 Human–Computer-Interaction group, Faculty of Media, Bauhaus-Universität Weimar, Bauhausstr. 11, 99423 Weimar, Germany

3 Danish Institute for Advanced Study, University of Southern Denmark, Fioniavej 34, 5230 Odense Denmark, Denmark



(a) The caregiver activates the cup

(b) The cup moves and blinks to attract the individual's attention

(c) The cup prototype rendering

(d) First prototype

Fig. 1 Envisioned use of cup, prototype design, and current working prototype

of the Art") that integrate blinking lights as a reminder to drink [3–6] or use speech [7]. It is based on the hypothesis that the movement of the cup itself (Fig. 1), along with light and a slight sound produced by the cup's vibration, provides a stronger trigger than only using lights. The use of speech is ethically problematic, as discussed in "Ethical Considerations". Moreover, our cup does not interfere with the habituated appearance of a cup or glass, and thus may be more appropriate for people with dementia, where it is important that objects look familiar and can be recognised [8, 9].

The cup aims to support the person's remaining ability for action, a principle in elderly care where it is aimed to keep residents active and involved as this can delay the (inevitable) decline [9–12]. Feedback from care staff as well as from geriatrics experts supported our idea.

In this paper, we describe the design of a working prototype (Fig. 3) that illustrates the concept and enables user tests ("Detailed Overview of Functionalities" and "Functionality Tests").

The use of robots in healthcare environments is an important area of development but also raises important ethical issues, especially with vulnerable people such as those affected by dementia. Ethicists fear that the robots designed for them benefit mostly caretakers and threaten their privacy, liberty, and dignity [13–15]. Unfortunately, most of these robots are still designed without consideration for these ethical issues [16]. In this paper, we include an ethical evaluation of the cup and give some recommendations for how to use the cup in a way that is ethically acceptable ("Ethical Considerations").

To define the optimal procedure for future quantitative tests, the routine and drinking habits at a care home in Denmark were observed and the cup was introduced to a few people to record the initial reactions. We discuss considerations made after the introductions on the cup's design, functionality, and future quantitative testing procedures ("Initial Observations and Thoughts About Redesign").

The paper is an extension of a conference paper [17]. While the technical parts are to a large degree identical, we added a rigorous reflection on different ethical dimensions connected to the Bibo-cup when applied in the context of people affected by dementia in "Ethical Considerations". Also, we report (see "Initial Observations and Thoughts About Redesign") on initial observations in a Danish care home where the Bibo-cup has been introduced.

State of the Art

Dehydration affects 20–30% of older adults and increases reported health issues [18]. Dehydration is even more perilous for people with dementia, as it poses one of the main, often less thought of, causes of death. More people with dementia, once they reach a late stage in the disease, die from cachexia or dehydration rather than of any other cause of death [19]. Dehydration has been found to be more severe in people with advanced cognitive impairments [20]. According to Xiao et al. [21], on average, 5.5 billion dollars are spent in the USA annually to treat hospitalisations caused by dehydration.

Dehydration in the elderly happens for multiple reasons. Fluid reserve is decreased compared to their younger selves, liquid loss is more frequent, and the sense of thirst is not as intensive [22]. A combination of these reasons, among others, can co-exist in a person causing severe dehydration.

Most of the solutions that encourage people to drink have taken the form of augmented bottles or cups (e.g., [4, 5, 7, 23–26]), while others take the form of add-ons to be combined with existing objects (e.g., [3, 6, 27]). The most common method seems to consist of grabbing the attention with a visual trigger through light effects (e.g., [3–6]), via an audio signal (e.g., [24]), or through a combination of both (e.g., [7, 25, 26]).

The option of using vibrations to attract attention has been utilised in Ozmo [23], a bottle that reminds you to drink by vibrating (which might constitute rather an audio or haptic signal). Visible movement as an attention trigger has been explored more explicitly with the Bionic water drinking reminder [27], an additional attachment to a cup, shaped as a butterfly, which uses a vibration motor to flap its wings when triggered, to attract attention. However, the cup itself does not move.

Several of these products offer additional functions, such as monitoring water consumption (e.g., [4, 5, 23, 25, 26]), the frequency of drinking (e.g., [7]), or keeping the temperature (e.g., [4, 5]). Some products are paired with applications that allow the monitoring of daily fluid consumption, record hydration history, and calculate personal hydration goals (e.g., [4, 5, 23]). Most existing products are general consumer products, and very few are aimed for elderly and persons affected by illnesses and offer specific functions for care, such as Drink Smart [25, 26], a cup connected to a digital care documentation, or Droplet [7], a dementia-friendly mug that alerts caregivers with flashes and attempts to attract the user's attention with sound recordings.

Ethicists have pointed to some ethical risks of using robots to care for elderly people. Yet, many robots are still developed with little ethical considerations. This increases the risk that robots that are not ethically acceptable will be developed and marketed. For example, PARO is a baby seal robot that reacts to touch and sound and that is used as a replacement for animals in zootherapy. Several studies have shown that its use brings several benefits, such as reducing stress and increasing socialisation [28, 29]. Nevertheless, PARO is criticised for deceiving and infantilising elderly people with dementia [30, 31]. Some claim that robots like PARO are therefore harmful and ought not to be used in such contexts [32]. Many ethicists, therefore, advocate for design processes that involve ethical considerations [16, 33, 34].

Product Description and Envisioned Use

Through a few iterations and feedback from experts in geriatrics and elderly care, a prototype was designed (Fig. 1b, c) as a proof of concept as well as demonstrator for planned user tests (Fig. 1d). As a general design constraint, the shape and look needed to be recognisable as a cup and look familiar, so that it can evoke spontaneous use as response from elderly residents with dementia. The cup is small enough in diameter and light enough to be handled easily. The possibility of adding a supplementary handle for residents with limited hand functionality was added as an option (Fig. 1c), based on recommendations from elderly care experts.

The cup consists of two parts. The lower part is made of coloured polyamid and houses all electronic components and sensors. A coloured cup is considered easier to perceive, as intense colours aid visual perception in people with dementia. At the moment, the cup is made from a photopolymer (VeroWhite) for a Stratasys Objet30 Prime 3D printer to enable iterations within tests and development. Detailed consideration was given to the upper part, which holds the beverage. A food-safe and transparent material is used to facilitate diffusing of the coloured light (Figs. 4b, 7) as well as to keep the appearance of a regular cup or glass.

The envisioned scenario of use is that care staff places the cup in the field of view of its user (usually on a table) and activates it via a switch. If the cup is not picked up for a (predetermined) time, it will start to move and blink, thereby alerting to its presence. This would then attract the attention of the resident, who perceives and recognises the cup, thereby prompting them to drink. The activation (movement and light) is executed in spaced-out intervals, to enable the intermittent drinking and avoid overly disturbing the resident. If the cup is not picked up, the activation will be repeated after a predetermined time has passed. If a pickup is detected, the cup stops moving and will restart the countdown for a subsequent activation at a later time.

The device can be configured and personalised according to the individual's needs via physical sliders (Fig. 2). Geriatrics experts recommended providing the ability for configuration, because of the differences in each stage and form of the disease, where each individual might react differently, which has an impact on how strong the visual and/or movement signal needs to be (or what would be too much). They also stressed that such controls need to be simple and physical tangible (not via a mobile app), since any caregiver (or temporary help) should be able to do this, and care staff often have little affinity with technology. The configurable parameters are the intensity of movement, intensity of blinking, and light colour.

If the resident picks up the cup, this is detected by an accelerometer. The cup then ceases to move, so that they can drink. When the cup is empty, the cup will repeatedly flash on and off in a predetermined colour to alert the stuff for refill as well as aid in liquid intake monitoring.

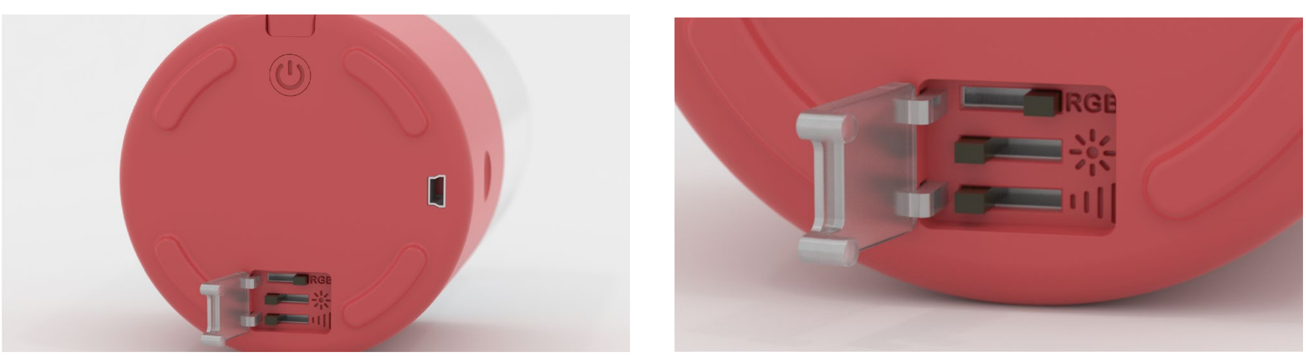
Detailed Overview of Functionalities

We now describe the cup functionalities and details of the mechanical and electronic realisation. This is structured along the core functionalities of our prototype: grabbing attention ("Grabbing Attention"); water level detection ("Water Level Detection"); activation, deactivation ("Activation and De-activation, Charging"); pick up detection ("Pick Up Detection"); configurability ("Configurability").

Grabbing Attention

Two actions are implemented to attract the attention of the residents: movement (and the implicit sound from its production), and coloured light impulses that create visual stimulation. These occur in bursts, to enable drinking in between those phases and to avoid over-stimulation. Ideas for sound output as an explicit signal were discarded and we aim for fairly subtle motor sounds. This is because care experts advised that if the cup is used, e.g., in the social setting of a care home's dining area or sitting/common room, this could overstimulate and annoy people (including the staff), in particular if several such cups are in use.

The movement of the cup is generated using a small 3V DC motor mounted in the bottom of the cup (Fig. 4a). A plastic lever is attached to the motor shaft. The end of the shaft holds a small steel puck which acts as an unbalanced Eccentric Rotating Mass (ERM) which generates instability resulting in a centripetal force, forcing the cup to rotate, and a centrifugal force away from the centre of the motor shaft. The motor rotates the lever arm at a variable speed, depending on the measured water contents of the cup (see "Water Level Detection"), generating the needed forces/vibrations to correctly rotate the cup, without spillage. With the eccentric rotation of the motor and of the cup itself, the cup moves on the table, changing its position and thus visually stimulating the resident. To avoid moving too far from the resident and prevent the cup falling off the table, the motor changes direction of rotation between activations, thus moving in opposite directions in consecutive bursts. The specific speed of the

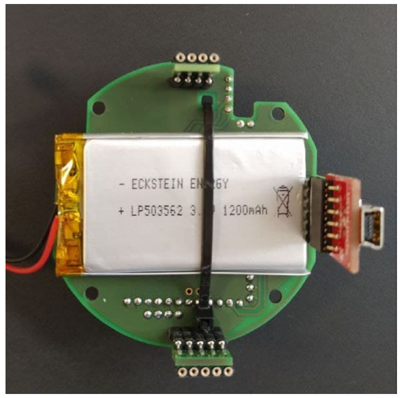


(a) Configuration and power on/off switches on the bottom

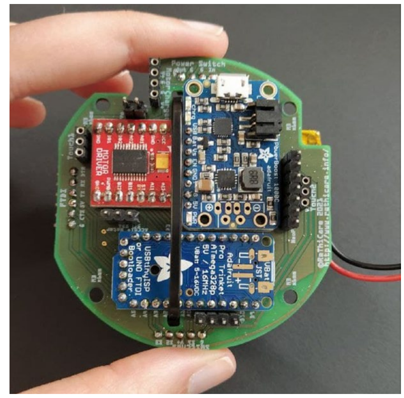
(b) Zoom in on configuration switches

Fig. 2 Activation and configuration switches

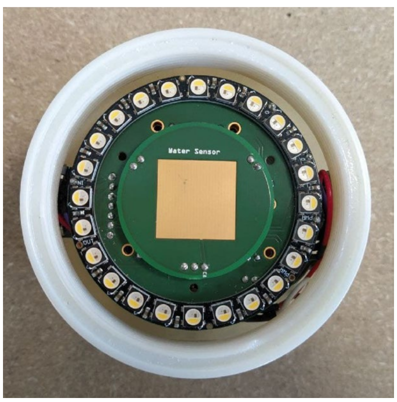
(a) Placement of Printed Circuit Board (PCB) 1 in cup



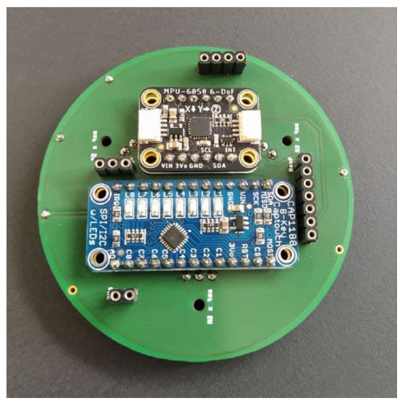
(b) PCB 1, side A. Battery, interface with switches, USB port



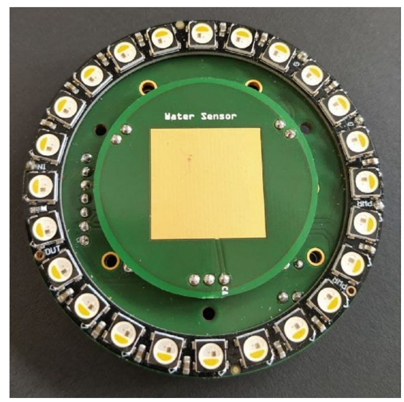
(c) PCB 1, side B. Microcontroller, motor driver, battery driver



(d) Placement of PCB 2 in cup



(e) PCB 2, side A. Accelerometer, touch sensor interface



(f) PCB 2, side B. LED ring, capacitive sensor

Fig. 3 Prototype components

motor at the respective water levels was determined based on lab tests (see "Water Level Detection").

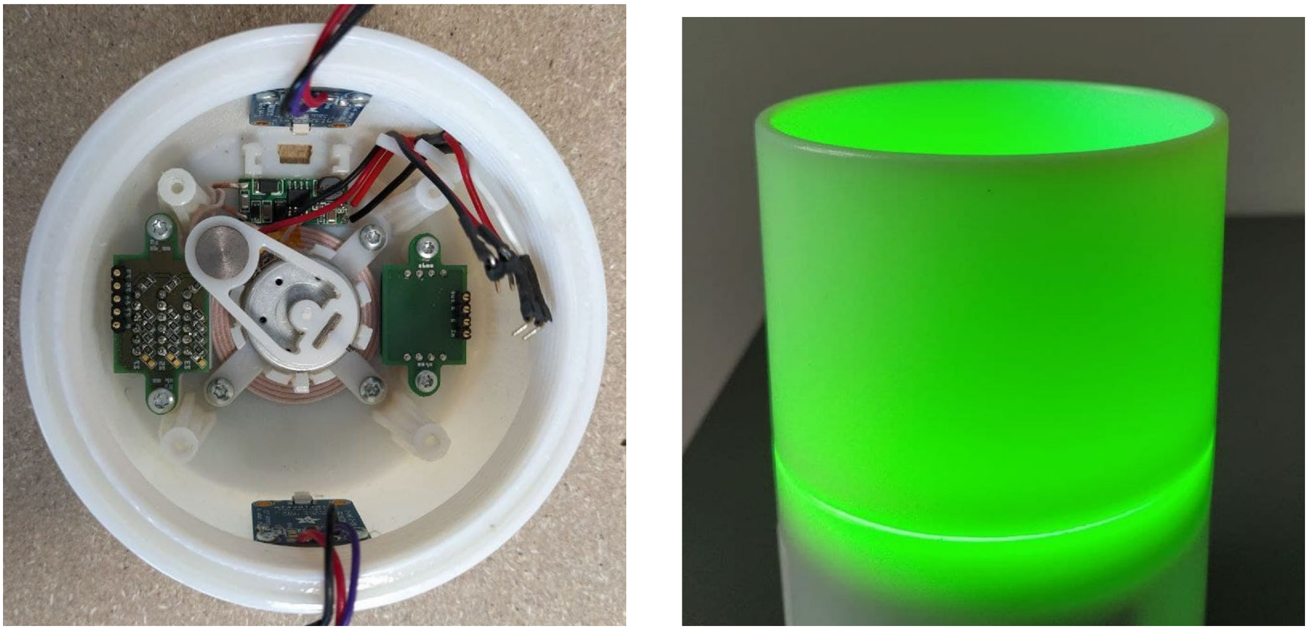
As a complementary way of attracting attention, the cup subtly blinks (Fig. 4b) when activated, using an Adafruit Neopixel ring (Fig. 3f). The colour and intensity of the light can be configured according to individual's needs as explained in "Configurability"; see (Fig. 2a). As a default, the colour red was chosen, as studies show that red or similarly intense hues increase liquid intake in people with dementia by ca. 80% [35].

Water Level Detection

Two approaches for water detection methods were explored, a capacitive sensor, that roughly detects the presence (not quantity) of water and a strain gauge bridge, which is also able to measure quantities. As the capacitive sensor functions without contact, it can be embedded in the plastic shell (Fig. 5a), and thus does not require waterproofing. The current version of the prototype works with a capacitive sensor.

An additional method for detection is currently in the final stages of development. The strain gauge method measures the weight of the water content in the cup. This information can be used to adjust the rotation speed of the motor making the cup move/rotate. The more water the cup contains, the faster the motor will spin, enabling movement even with the added weight.

The cup is comprised of a top and a bottom half, where the bottom contains the electronics. The top half, which contains the water, is fitted with a flexible bottom made of



(a) The bottom of the cup containing the ERM mechanism for the cup movement

(b) Cup blinking with a green light, diffused in water and visible through the material

Fig. 4 Cup attention grabbing functions (dancing and blinking)

food-approved plastic, and has four strain gauges glued to it (Fig. 5b). The strain gauges circuit is set up as a full Wheatstone bridge [36]. Physically, this appears as strain gauges in pairs in two circles (see Fig. 5b). A pair of strain gauges in this case is two strain gauges placed with an equal distance from the centre of the flexible bottom mirroring each other, which makes up the full Wheatstone bridge. A full Wheatstone bridge is needed to neutralise the effects of temperature changes which the strain gauges are sensitive to. The strain gauges deform due to the increased weight of water in the cup, thus changing resistance, making it possible to algorithmically correlate changes in strain gauge resistance to the change in weight. To determine the weight of the cup content, the voltage output from the strain gauge Wheatstone bridge is correlated to a unit of weight. To do this, a steel cylinder (Fig. 5c) is fitted with a 1 mm-thick PETG plastic bottom (Fig. 5b), with the four strain gauges mounted on it. The Wheatstone bridge is connected to a micro-controller which collects the data.

Activation and De-Activation, Charging

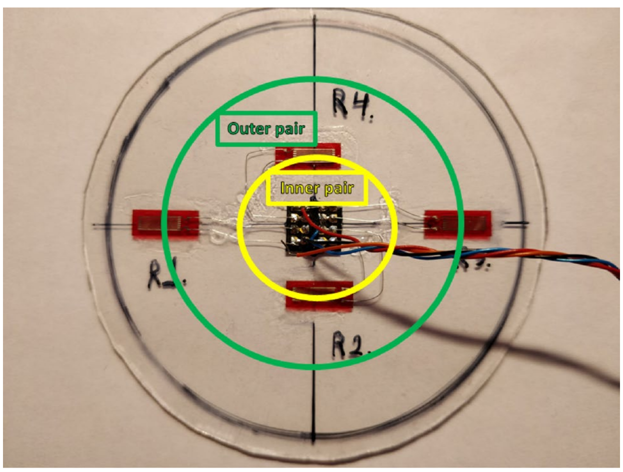
The activation of the cup is done in two steps. First, a button is pushed on the cup's bottom (Fig. 2a). Once switched on, the LED ring blinks briefly, its colour indicating the battery status. After the cup flashes with a green light, indicating sufficient battery power, the cup can be placed in front of the user, and is then activated by touching the two opposite finger recesses simultaneously (Fig. 6a), thus preventing unintentional activation.

The main process then starts and will continue only if the cup contains fluid and is not grabbed. Once the battery is low, this stops and the LED ring starts to blink red. The cup must then be switched off by pressing the ON/OFF button at the bottom of the cup and placed on its induction charging base (Fig. 6b). Although less effective than USB-charging, induction was chosen for its practicality and ease of use.

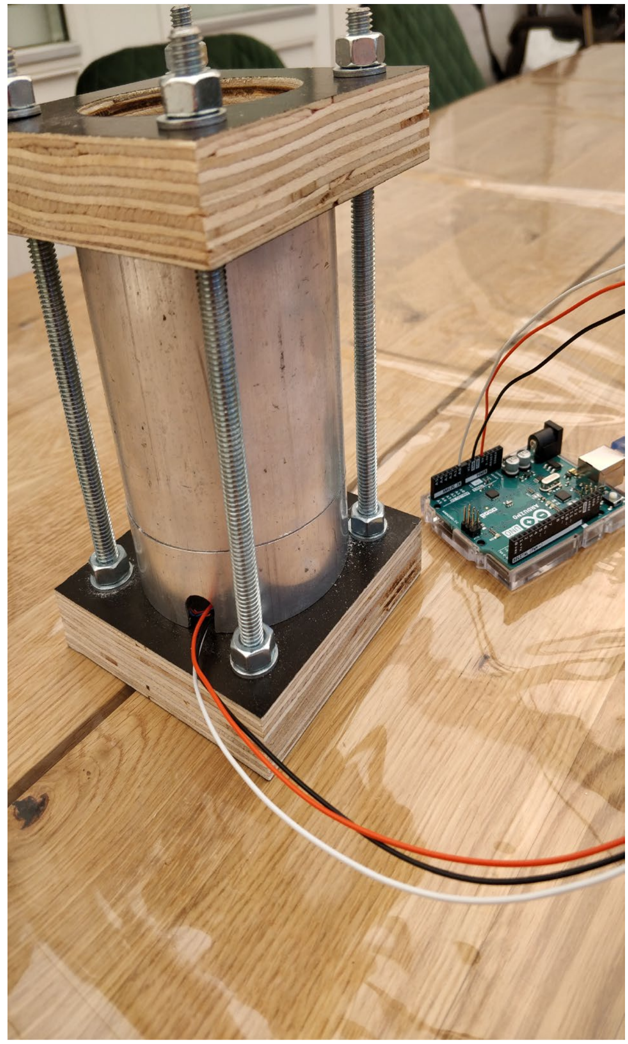
Pick Up Detection

The vibration or movement of the cup should not continue when taken in hand. The accelerometer (Fig. 3e) enables the monitoring of any movement in elevation and change in inclination; two parameters innate to handling a drinking cup, first lifting the cup from the table and then inclining it to drink. Together, these parameters make it possible to detect if the cup is picked up, and then to stop the motor and the LED signal. If the cup is taken up before the movement even starts, the whole cycle is reset once the accelerometer does no longer detect any movement.

(a) Square capacitive sensor embedded in plastic shell (in center)



(b) Flexible bottom with physical wheat-stone bridge, outer strain gauge pair (green) inner strain gauge pair (yellow)



(c) Strain gauge water content measuring test setup

Fig. 5 Water level detection methods

Configurability

Geriatrics experts and care staff, who provided feedback on our concept, recommended that it should be quick and easy for the care staff to reconfigure the three key parameters—LED colour, LED brightness, and motor speed—according to the resident's needs. As care staff may not be familiar with technological applications and since there are usually different staff members involved, including temporary helpers, we discarded the idea for a mobile app, prioritising work-efficiency, and user-friendliness, and opted for on-product analogue/physical configuration modalities. To save space, we chose three slide switches (Fig. 2a), with four positions for configuring LED colour (red, yellow, orange, and blue), LED brightness, and motor speed. The colours were discussed and decided with the help of care staff, aiming to associate colours with different beverages, e.g., blue with water, red, and yellow with different juice flavours. After each colour change, the LED ring blinks in the selected colour as feedback (Fig. 7a, b); after an LED brightness change, the LED will blink with the currently selected colour in

(a) Cup touch activation (b) Charging Platform

Fig. 6 Cup secondary activation method and inductive charging platform

(a) Yellow (b) Blue (c) Red, high intensity (d) Red, medium intensity

Fig. 7 Light colours and intensities

the chosen intensity (Fig. 7c, d); and a change in motor speed is shown with a blink in white colour with different intensities, to indicate the intensity of the movement (a decision to refrain from movement in the configuration process was taken). Following recommendations by care staff, we plan to conceal these switches with a safety strip (Fig. 2b) to avoid inadvertent changes of the configuration by the residents.

Functionality Tests

At its current state, the prototype was tested for functionality in the lab. The previously described capabilities have been implemented. The achieved results for the three main functionalities (visual signals, movement, and water level detection are discussed in the following sections.

Visual Signals

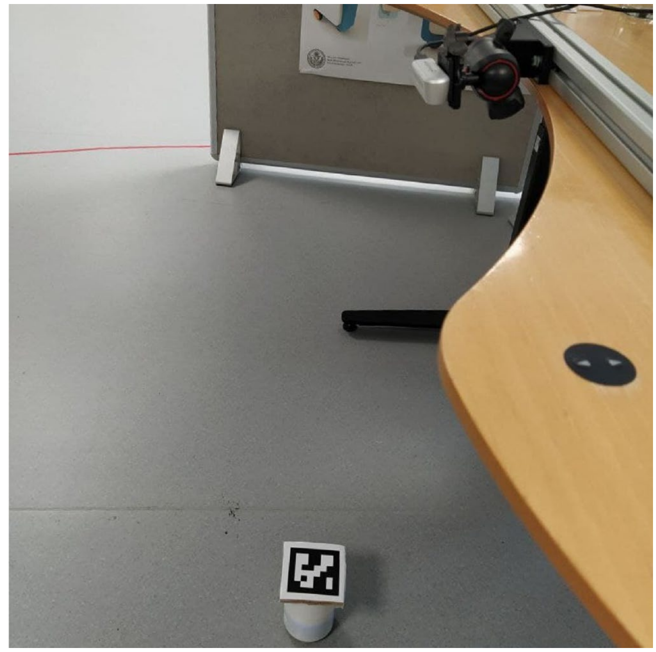
As shown in Fig. 7, the different hues and light intensities diffused through the cup are clearly visible. The light bursts are not intense, but fade in and out, as advised by care experts. This is because intense and rapid blinking is feared to startle and overstimulate patients.

Movement

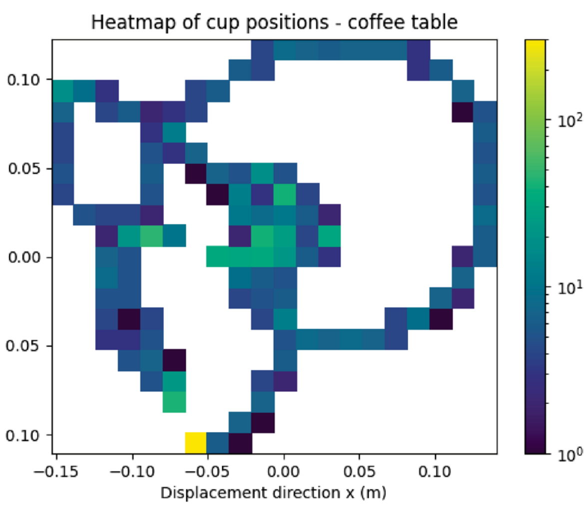
The cup rotates in opposite directions in subsequent turns. This leads to displacement in a constrained area and ensures that the cup does not fall off the table, given that it is placed within a minimum predefined distance from the edge before activation.

To quantify the movement, structured experiments were executed. The cup containing 150 ml of water, fitted with an Aruco marker, was activated and left to translate freely,

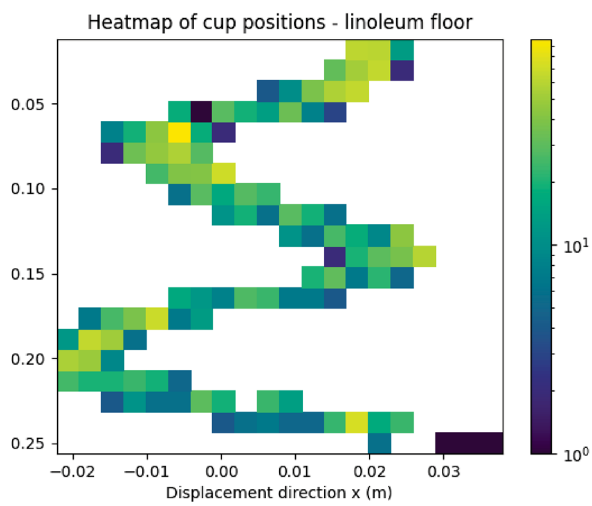
(a) Experimental Setup - top



(b) Experimental Setup - side



(c) Cup positions and their frequency - coffee table



(d) Cup positions and their frequency - linoleum flooring

Fig. 8 Movement quantification experiments

as it would in a normal activation. A stationary camera placed above the area was used to record the movement (Fig. 8a, b). The Aruco marker was detected and used to extract the exact position of the cup relative to the camera. This process was repeated ten times to acquire sufficient measurements. The translation of the cup depends, as expected, on the intensity of the motor rotation set by the configuration switches ("Configurability"). The movement was tested in two different surfaces, a wooden coffee table and linoleum flooring (Fig. 8c, d). The heatmap illustrates the positions of the cup on the surface and the frequency of the occupation of the specific position. The translation was found to be confined to an area of 0.08 m^2 for the highest intensity of movement on the coffee table and much lower on linoleum flooring (0.01 m^2).

Considerations on controlling or restricting the movement of the cup have been made for later development. First, a beacon to detect whether the cup has moved over a “movement safe area” threshold is considered. In case where the cup covers a larger distance than initially allowed, the cup should seize activation and alert the staff for repositioning. Additionally, the investigation of a controlled movement generation through additional motors is intended.

Water Level Detection

The current prototype includes a capacitive sensor for water detection. The strain gauge method is, however, developed and planned to be included in a future second prototype, to test both possibilities. In laboratory tests, the strain gauges have proven to enable inferring the volume of water in the cup, with relative accuracy.

The relation between voltage and water level was determined as follows: two test procedures were performed as preparation for water level detection. In the first, approximately 40 ml of water was added in the test setup (Fig. 5c), then the cup took 1000 measurements/samples with a frequency of 4 Hz, and this took approximately 2.5 min. Then, another 40 ml was added, and the procedure was repeated until the cup was full (i.e., six times). The next procedure was the reverse, where 40 ml was removed with a sample interval of 1000 samples. The process was repeated multiple times in different days and times of the day, for thorough data collection and to ensure that climatic changes were not of effect.

Spikes and noise in the readings are removed using interpolation. A mean measurement value is calculated for each sample set of each water level, and a linear regression model is fitted to the readings. Each procedure is fitted separately to obtain linear model coefficients. The mean coefficients are then calculated. It was observed that a stable linear function can describe the relation between voltage and water level, with a small instability when the water is below 50 ml. The coefficients are plotted, along with the calculated mean coefficients (Fig. 9). The mean coefficients can then be used real time in the cup to output the water level depending on the measured voltage. This calculation is used to adjust the RPM of the motor (“Grabbing Attention”). Less samples could also suffice if needed; as a minimum, 700 samples have proven adequate.

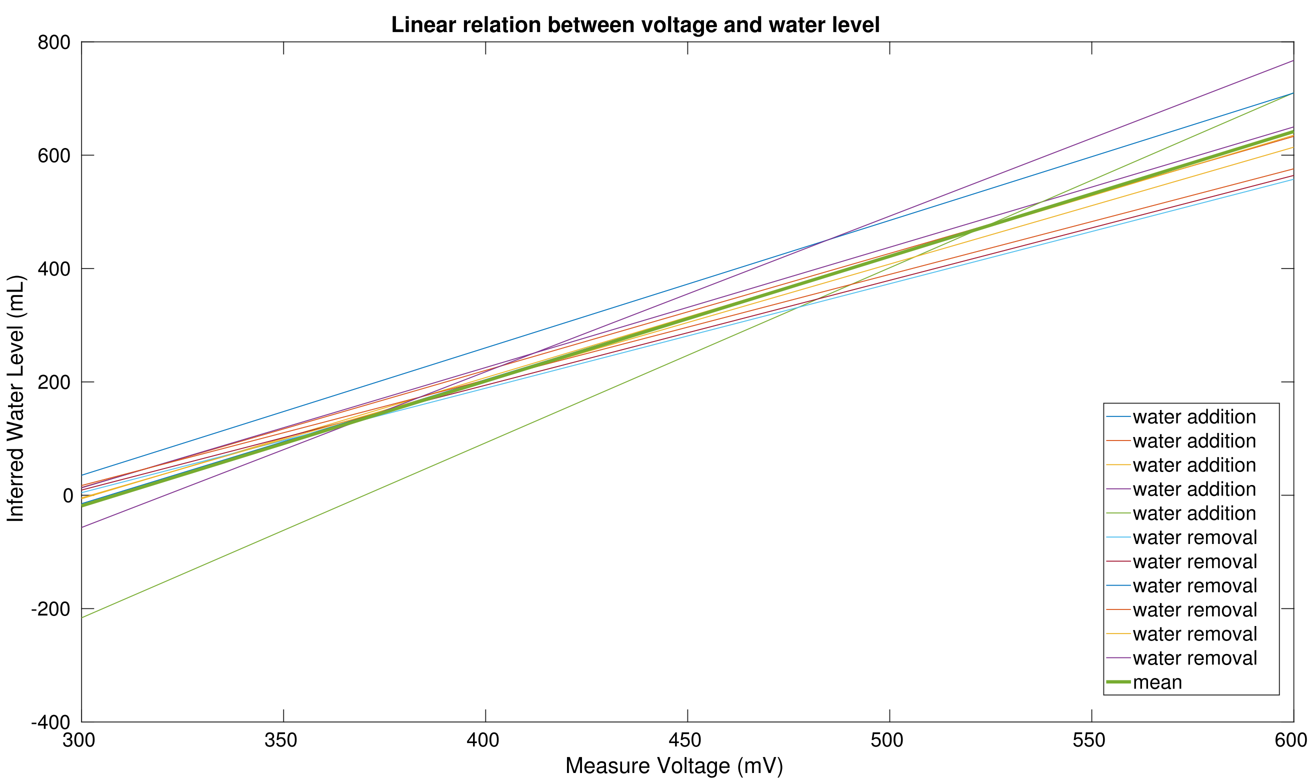


Fig. 9 Linear regressions of voltage-water level measurements (five repetitions) and calculated mean

Ethical Considerations

The use of robots and other intelligent assistive technologies in healthcare is often criticised for the ethical risks it involves, especially for vulnerable patients such as people affected by dementia. The main ethical risks that have been identified are the following ones [13–15]:

1. Reduced Human Contact: If robots are used to perform tasks usually performed by human caretakers or relatives, it might reduce the workload of caretakers but also result in a loss of human contact for people who already tend to be isolated. One concern that is prevalent is that the use of robots benefits caretakers but not patients themselves [13].
2. Privacy: Elderly people can feel that the robot is intruding their privacy if an assistive robot follows them everywhere or enters their bedroom without asking for permission first. Furthermore, certain robots can record sensitive personal information about patients such as their geolocation or even images of them in the privacy of their bedroom or bathroom. There are concerns regarding the confidentiality of these data [37].
3. Deception and Infantilisation: The behaviour of some social robots can encourage elderly people with dementia to wrongly believe that they have a relationship with a robot and that the robot is a person or an animal. Some also think that the use of a robot such as PARO that looks like a stuffed animal is infantilising and based on the premise that elderly people with dementia become children again [30, 31].
4. Loss of Control and Loss of Personal Liberty: Some assistive devices aim at keeping the elderly person safe, for example, by preventing them to do dangerous actions. Although this aims at enabling people with dementia to stay at home longer and thereby preserving their autonomy, it can also result in a sense of loss of control and personal liberty if the robot controls what they can and cannot do [37].
5. Risk of Harm and Responsibility: Robots need to be safe for users and their risk of harm should be minimised. In addition, the question of responsibility in case of malfunction and harm should be addressed.

These risks, as well as other less prevalent ones, need to be evaluated and minimised for the use of robots to be ethically acceptable when applied in the context of people affected by dementia. However, Ienca et al. [16] found in a review that two-thirds (67%) of intelligent assistive technologies are developed without “explicit ethical consideration”. In this section, we undertake to assess the above mentioned ethical risks of using Bibo.

1. Reduced Human Contact: One might worry that the cup is more beneficial for the staff—who is relieved from the task of monitoring the drinking of the residents—rather than for the residents themselves who lose that human contact. However, this cup was developed, because we observed that caretakers already did not have time to monitor their residents’ drink intake. In that sense, the cup does not reduce human contact for the residents and benefits them by improving their hydration. Nevertheless, this suggests that the cup should not be used in environments where there is a caretaker who is able to remind the resident to drink personally, as it is in general the case during breakfast and lunchtime in elderly care institutions. Furthermore, when possible, measures that increase the time that caretakers spend directly with residents should be prioritised.
2. Privacy: The resident’s privacy is not at risk with the cup, because it registers very little and no sensitive information. At the moment, the cup only detects if there is water in it and if it is being picked up to determine if it should be turned on or not, but that information is not registered. In the future, we would like the cup to monitor the amount of water that is being drunk. However, the cup will not record any information regarding who is drinking it. Therefore, only those who know who used the cup, most likely the caretakers, will be able to interpret that information. In the case of caretakers, the cup will not give them access to new information since they are the ones serving the drinks. Furthermore, the data registered by the cup will not always be reliable, since it does not differentiate between water being drunk and spilled. For these reasons, we do not think that the cup would pose a significant threat to the privacy of their users.
3. Infantilisation and Deception: The cup has been designed to look as much as possible like a regular cup with the top part being circular and transparent. Although the bottom part distinguishes it from regular cups, it does not look like a toy. Furthermore, its design is not based on the premise that elderly people with dementia are like children. The lights and the movements of the cup mainly aim at attracting the attention of the resident to the cup and not to make it seem like toy. Furthermore, it does not invite deception, since it looks exactly as it is: a cup to drink from that also moves and lights up. In that regard, Bibo might be a better option than the speaking cup [7], designed to have the voice of a relative or caretaker recorded which reminds the resident to drink. This might confuse the resident or deceive them in thinking that the person is there with them.
4. Loss of Control and Personal Liberty: The cup does not restrict the movement of users. However, they might think that their personal liberty is restricted if they feel

forced to drink from the cup, although they do not want to. This raises the issue of consent that is especially difficult when working with people affected by dementia, since they often do not have the ability to fully comprehend what the robot is, what it does, and what it entails for them. Nevertheless, even if we cannot obtain full consent for the use of the cup, some form of consent is often accessible. In the case of the cup, many residents still have the ability to understand that it is a cup they can drink from and that it will light up and move to remind them to drink. It is, therefore, important to introduce the cup to them, explain to them what it is, and ask them if they want to use it or not. A "no" should, of course, be respected. Furthermore, even if cognitive and communicative abilities are further restricted, residents who are able to use the cup will usually still be able to show discontent when presented with the cup and manifest their refusal to drink from it or their annoyance towards it. For example, we have observed a person that after a while moved the cup away from themselves showing signs of discomfort. We then immediately asked whether we should remove the cup and did so, once this was confirmed. Of course, in such cases, the cup should not be used. Another way to foster consent as much as possible is to have an alternative (a regular glass) available, so that they do not feel forced to drink from the cup if they want to drink. We are also giving a special attention to the parameters of the cup (how long it lights up and moves and to what intensity). Our aim is that it attracts the resident's attention but is not an annoyance that they can only avoid by drinking from the cup, as this would be another way to force them to drink from the cup.

5. Risk of Harm and Responsibility: The cup has been designed, so that it bears minimal risk for its user. The material is safe to drink from and presents no risk of electrocution. The main negative outcome that is risked with using the cup is spilling its content. Spilling can involve discomfort but does not harm the user—except when used with hot beverages—which should be avoided.

Our ethical analysis of the cup suggests that the ethical risks of using the cup are low and that it is ethically acceptable to use it as long as the recommendations outlined above are respected.

Initial Observations and Thoughts About Redesign

With the future quantitative tests in mind, small-scale pretests were carried out with a collaborative care home. Through these, we intended to study every day habits in the home (described in "Observation of Drinking Habits) and briefly introduce the cup to a few residents to collect initial reactions ("Introduction of Bibo). We subsequently discuss the outcomes of the tests and considerations for future changes in design and functionality and the plans for future testing ("Outcome from Initial Tests, Outcome from Initial Tests).

Observation of Drinking Habits

To establish the optimal conditions in which the cup should be tested in the care home, an average day in the home was observed by the researchers. The observations were conducted with two goals in mind. First, understanding the general routine, the times people were left alone, times they spend with a staff member, as well as the typical drinking habits of the residents. Second, we wanted to identify possible participants who could benefit from the Bibo-cup.

We discovered that during the afternoon, many residents spend time by themselves, either in their rooms or common areas. Beverages are provided by the staff but supervision and encouragement to drink is minimal as the staff is busy tending to the residents' needs. Consequently, many residents do not drink, even though a beverage is available. In mid-afternoon, they are provided with dessert and drinks. Despite eating all their dessert, the beverages are not always consumed. This is identified as an ideal situation for testing the drinking encouragement effect of the cup. Other eligible times could be the interval between breakfast and lunch or after dinner. All these are times where at least some of the residents spend time alone and do not receive a strong stimulus to drink. In other times, for example meal times, residents are surrounded by care givers who regularly encourage drinking, meeting the needs of liquid consumption. For the purposes of testing, residents were only given the cup during the time they spent in the common areas and not during the time they spent in their rooms. This aimed at refraining from any invasion of their private space.

As the population of the care home has diverse forms and stages of dementia, the physical and cognitive abilities of the residents vary. For a resident to profit from the Bibo-cup, they should be able to consume beverages themselves without help from the staff. Individuals with a history of neglecting drinking are preferred, as they would resemble the target user group. According to our observations and consultations from the staff to supplement our information, we have identified that approximately 50% of the residents could benefit from the cup and could therefore be part of the study.

Introduction of Bibo

The cup was introduced to five residents on two different occasions. The residents' behaviour was observed. Primarily, the reactions to the cup and its movement was monitored. A special attention was taken to ensure that residents were not afraid of the cup and were not irritated. The cup was given to the residents by the caregivers who explained that it was a new cup they have and asked whether they wanted to try it out. The first interaction with the cup was closely observed to make sure that residents were comfortable with it, and afterwards, we attempted to not interfere with them as much as possible.

A few free parameters were tried to determine the most fitting values for long-term testing. The intensity of vibration and movement was varied to find the magnitude needed for movement of the cup in the visual field without causing irritation or fear. The interval between activations was also considered, with more and less frequent impulses.

After the introduction of the cup to one user, the staff mentioned how fun it was that their new cup was so bright and playful. Subsequently, the resident drunk from the cup more times over time even after the caregiver had left.

A second individual used the cup three times by themselves. In the next attempt to drink, the cup vibrated and it did not stop vibrating when they tried to pick it up. This startled the user and they were hesitant to use the cup again later. When provided with a normal glass, they opted to use that one instead.

In one case, after the first introduction of the cup to a resident, both the Bibo-cup and an average glass were provided with the same beverage. The resident then decided to drink from our cup. After a while, when the caregiver refilled only the glass, the resident emptied the content of the glass in the Bibo-cup and drank from it instead.

Outcome from Initial Tests

Considering the knowledge acquired from the initial tests, it was decided that a more robust handle version of the cup should be available. Some residents required more effort to hold the cup with one hand. Therefore, a handle would be helpful. A robust but detachable appendix with a handle is prepared to be added and removed according to the residents needs (Fig. 10). A two-handle version of the appendix was considered, but we decided against it to avoid an infantilising appearance.

The appearance of the cup is also reconsidered. As we try to keep the motion to a limited magnitude, both for safety reasons as well as to avoid irritation of the user and other residents, modifications to the cup's design are considered such as small modifications on the bottom of the cup, e.g., stripes, or an added pattern on the transparent part of Bibo (Fig. 11). These are thought to potentially enhance the rotation visually. Although the imitation of crystal glass pattern might appear deceptive, we think that it is, nevertheless, ethically acceptable. First, it does not deceive users about what kind of thing the cup is—a cup. Second, it might benefit them by increasing acceptance of the cup. This has to be tested. The patterns on the cup will be further augmented with the addition of the handle appendix when needed.

Fig. 10 Detachable handle appendix

After consultation with the staff, a variable duration of the activation is also considered. For future testing, it is decided that the third slider switch will also be used to modify the duration of the activation. This was desired as individuals have different reaction times and would need longer to register the light and movement. Activation duration between 2 and 8 s will be tested. This should be limited as to respect matters of consent as outlined previously in the ethical considerations. The interval between activations was decided to be 7 min after input from staff and observed behaviour.

To avoid startling any user, the cup should not vibrate while in hand. This is addressed in two ways for the next tests. The activation process changes from simultaneous light and movement to prolonged illumination with a limited burst of movement in the beginning of the cycle. The combination of the two will attract attention, and while the movement will stop to enable convenient grabbing, the light will persist to keep the potential user engaged. A periodic cycle is still implemented, with the light being turned off to ensure maximum contrast during activation as well as limit disturbance. Additionally, the threshold upon which a pickup is detected from the IMU is lowered, to detect the pick-up attempt swiftly. Additionally, the IMU data could be used

(a) Imitation of crystal glass (b) Striped design of bottom half

Fig. 11 Modifications considered to enhance visual stimulation

to possibly identify whether a user is attempting to push the cup away, thus ensuring consent of participation in the study.

Plans for Further Testing

In the future, the care home will be visited a few more times for observations, to assure that the conclusions drawn were not due to chance as well as to acquire new knowledge.

The cup will then be taken through longer testing to evaluate its impact. The quantity of liquid intake using an average glass from the care home and the Bibo-cup will be compared. Different beverages will be considered, following the routine of the care home, not taking into account any alcohol or coffee consumption. The experiments will follow a three stage structure. The first stage will establish a baseline of drinking habits. Stage 2 will measure the effect of Bibo on the drinking habits. Stage 3 will be identical to stage 2 but at a later time, to establish whether the novelty effect has an influence on the results.

Before the cup is introduced to any individual, a two-step procedure will take place to ensure that the ethical recommendations outlined above are respected. An information sheet will be given to all relatives beforehand and a simple information sheet with pictures will be given to the residents. The product and its purpose will be explained to them as well as the fact that they are not required to participate and they can withdraw at any time. This will be done to the best of our abilities, acknowledging that the content might not be understood in its entirety. If, at any moment, a resident appear reluctant to participate, they will not be included in the study.

The cup will then be given to residents one at a time. A researcher will be close for the first interaction to ensure safety and after that will retract out of sight, but still observing and ready to intervene at any moment. This ensures limited interference and conveyance of the feeling of being observed but guarantees a swift response in any case of discomfort. A normal glass should also be available at all times on the table in case the individual will prefer to drink from that as we want to refrain from preventing them from drinking in case they are uncomfortable with Bibo. This also protects their right of choice in participation in the study, even if not explicitly stated. All individuals participants of the study will also be observed for an equal amount of time while using a glass normally used in the care home as a control measurement.

These conditions were discussed with the Research Ethics Committee of the University of Southern Denmark. After analysis and outlining of testing procedure, the board has granted ethical approval for testing.

Conclusion and Outlook

We developed a prototype of a moving cup that should remind people affected by dementia to drink, a problem that is recognised in long-term care and which is nowadays addressed by care staff.

We reflected on different ethical dimensions connected to the use of the cup in dementia care and we made first in situ observations in a Danish care home. The cup was introduced to five different residents on 2 consecutive days for a limited amount of time. The cup was generally well received and the obtained observations helped us understand the importance of different technical parameters, such as timing and intensity of movement and appearance of the cup.

We will now start extensive testing to further optimise the design of the cup and its movement and to evaluate its effect on the liquid intake.

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Data availability Due to GDPR restrictions, the data is not publicly available.

Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

Ethics Approval This was obtained from the Research Ethics Committee of the University of Southern Denmark.

References

1. Begum MN, Johnson CS. A review of the literature on dehydration in the institutionalized elderly. e-SPEN. 2010;5(1):47–53.
2. Lavizzo-Mourey R, Johnson J, Stolley P. Risk factors for dehydration among elderly nursing home residents. J Am Geriatr Soc. 1988;36(3):213–8.
3. Ulla. 2021. https://www.ulla.io/.
4. Hidrate Spark Steel. 2021. https://hidratespark.com/.
5. Equa Smart. 2021. https://myglassbottle.de/.
6. Drink On. 2021. https://msd-projekte.de/schulz/drink-on/.
7. Droplet. 2021. https://www.droplet-hydration.com/products/.
8. Bozeat S, Ralph MAL, Patterson K, Hodges JR. The influence of personal familiarity and context on object use in semantic dementia. Neurocase. 2002;8(1–2):127–34. https://doi.org/10.1093/neucas/8.1.127. (**PMID: 11997491**).
9. Harrison BE, Son G-R, Kim J, Whall AL. Preserved implicit memory in dementia: a potential model for care. Am J Alzheimer's Dis Other Dementias. 2007;22:286–93.
10. Menner H. Aktivierende und Reaktivierende Pflege. Vienna: Springer; 2004. p. 23–34. https://doi.org/10.1007/978-3-7091-6717-5_.
11. Crawford H, Anderson S, TeKamp R, Chatzikiriakos V, Osborne D. A review of the literature on dehydration in the institutionalized elderly. Healthcare Manag Forum. 2012;25(1):4–15. https://doi.org/10.1016/j.hcmf.2011.12.002.
12. Bozeat S, Patterson K, Hodges J. Relearning object use in semantic dementia. Neuropsychol Rehabilit. 2004;14(3):351–63. https://doi.org/10.1080/09602010343000264.
13. Sharkey A, Sharkey N. Granny and the robots: ethical issues in robot care for the elderly. Ethics Inf Technol. 2012;14(1):27–40.
14. Vallor S. Carebots and caregivers: sustaining the ethical ideal of care in the twenty-first century. Philos Technol. 2011;24(3):251–68.
15. Ienca M, Jotterand F, Vică C, Elger B. Social and assistive robotics in dementia care: ethical recommendations for research and practice. Int J Soc Robot. 2016;8(4):565–73.
16. Ienca M, Wangmo T, Jotterand F, Kressig RW, Elger B. Ethical design of intelligent assistive technologies for dementia: a descriptive review. Sci Eng Ethics. 2018;24(4):1035–55.
17. Kollakidou A, Lefeuvre K, Zarp CS, Palinko O, Krüger N, Hornecker E. Bibo the dancing cup: reminding people with dementia to drink. In: ICT for health, accessibility and wellbeing: first international conference, IHAW 2021, Larnaca, Cyprus, November 8–9, 2021, Revised Selected Papers. 2022. p. 127.
18. Miller HJ. Dehydration in the older adult. J Gerontol Nurs. 2015;41(9):8–13.
19. Koopmans RT, van der Sterren KJ, Van der Steen JT. The 'natural'endpoint of dementia: death from cachexia or dehydration following palliative care? Int J Geriatr Psychiatry. 2007;22(4):350–5.
20. Lauriola M, Mangiacotti A, D'Onofrio G, Cascavilla L, Paris F, Paroni G, Seripa D, Greco A, Sancarlo D. Neurocognitive disorders and dehydration in older patients: clinical experience supports the hydromolecular hypothesis of dementia. Nutrients. 2018;10(5):562.
21. Xiao H, Barber J, Campbell ES. Economic burden of dehydration among hospitalized elderly patients. Am J Health Syst Pharm. 2004;61(23):2534–40.

22. Hooper L, Bunn D, Jimoh FO, Fairweather-Tait SJ. Water-loss dehydration and aging. Mech Ageing Dev. 2014;136:50–8.
23. Ozmo. 2021. https://www.ozmo.io/.
24. Boyuan C. Healthful drinking reminder cup (China Patent CN000201822482U, Application date: February 20, 2010). https://depatisnet.dpma.de/DepatisNet/depatisnet?action=bibdat&docid=CN000201822482U.
25. Haslinger-Baumann E, Korak G, Werner F. Drink smart: dehydratation wirksam vorbeugen. Pflegez. 2020;73:52–5. https://doi.org/10.1007/s41906-020-0740-9.
26. Haslinger-Baumann E, Lilgenau A, Gugenberger K, Korak G, Geyer S, Unterweger U, Tiefenbacher S, Werner F. Development of an intelligent drinking system for the prevention of dehydration in old age.2017. p. 31–34.
27. Xioadong L. Bionic water drinking reminder (China Patent CN000209993092U, Application date: June 12, 2019). https://depatisnet.dpma.de/DepatisNet/depatisnet?action=bibdat &docid=CN000209993092U.
28. Hung L, Liu C, Woldum E, Au-Yeung A, Berndt A, Wallsworth C, Horne N, Gregorio M, Mann J, Chaudhury H. The benefits of and barriers to using a social robot paro in care settings: a scoping review. BMC Geriatr. 2019;19(1):1–10.
29. Kang HS, Makimoto K, Konno R, Koh IS. Review of outcome measures in paro robot intervention studies for dementia care. Geriatr Nurs. 2020;41(3):207–14.
30. Sharkey A, Sharkey N. We need to talk about deception in social robotics! Ethics Inf Technol. 2021;23(3):309–16.
31. Sharkey A, Wood N. The paro seal robot: demeaning or enabling. In: Proceedings of AISB, vol. 36. 2014. p. 2014.
32. Sparrow R, Sparrow L. In the hands of machines? The future of aged care. Minds Mach. 2006;16(2):141–61.
33. Seibt J, Damholdt MF, Vestergaard C. Integrative social robotics, value-driven design, and transdisciplinarity. Interact Stud. 2020;21(1):111–44.
34. Van Wynsberghe A. Designing robots for care: care centered value-sensitive design. Sci Eng Ethics. 2013;19(2):407–33.
35. Dunne TE, Neargarder SA, Cipolloni PB, Cronin-Golomb A. Visual contrast enhances food and liquid intake in advanced Alzheimer's disease. Clin Nutr. 2004;23(4):533–8. https://doi.org/10.1016/j.clnu.2003.09.015.
36. Hoffmann K. Applying the wheatstone bridge circuit. Darmstadt: HBM Germany; 1974.
37. Sharkey N, Sharkey A. 17 the rights and wrongs of robot care. Robot ethics: the ethical and social implications of robotics. 2011. p. 267.