Dynamorph: Montessori Inspired Design for Seniors with Dementia Living in Long-Term Care Facilities

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Abstract. Seniors with dementia living in nursing homes are often faced with boredom and loneliness due to lack of meaningful engagement and personalized activities. We applied Montessori method to design an interactive table for elderly home residents and evaluated the design with four female residents and a nurse. This method offers a range of levelled interactions to meet the needs at different stages and cognitive decline levels of the residents with dementia. The table initiates interaction with an increasing level of complexity that magnifies the rewarding effects and social connectedness among the residents. The qualitative evaluation during a pilot study indicated that the interactions with the table reduced agitation of the elderly participants and increased the instances of positive social behaviours.

Keywords: Dementia · Interaction design · Montessori method
Long-term care · Nursing home

1 Introduction

Dementia is a global problem that affects 47.5 million people and each year 7.7 million new cases are reported [1]. The symptoms of dementia are a decline of cognitive function, language abilities, mobility and memory loss, and varies with every individual. Although the progress can be slow, from months to years or decades, it will severely influence one's ability to live an independent life. Therefore, patients need help from informal caregivers or, more often, care facilities. In dementia nursing homes, residents often suffer from lack of activity and stimulation [2], which could result in boredom [3], agitation or other discomforts [4]. Engagement is defined as 'the act of being occupied or involved with an external stimulus' by Cohen-Mansfield [5]. It proves to have a positive effect as it decreases boredom or agitation. During the past decades, different kinds of non-pharmacological interventions for dementia have been studied in order to provide adequate stimulation [6]. However, limited by the number

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of qualified personnel and by implementation difficulties, interventions often took place in a group without considering the personal conditions of seniors with dementia.

Customized or personalized stimulations and activities based on the cognitive level or the personal experiences of dementia patients proved can decrease agitation and dementia related problematic behaviour significantly [7–9]. An example of such applications is *CIRCA* [10]. *CIRCA* is a touch screen based interaction that uses video, music, pictures and text to help persons with dementia and their caregivers to have more personalised and engaging conversations. Tailored Activity Program (*TAP*) [11] is another example of customized activity for dementia patients. The program aims to identify interests and capabilities of persons with dementia, and developed occupational therapy intervention especially tailored for individual profiles to reduce some unwanted behavioural symptoms. Due to decreasing cognitive functions of individuals with dementia, related research suggests that being active can enhance social connectedness, the consistency of self-identity, bring positive affections and decrease frustrations [12, 13]. Meaningful activities for nursing home residents with dementia was shown to reduce agitation, decrease behavioural problems, and enhance the quality of life [14].

In this paper, we present *Dynamorph*, a Montessori method inspired interactive table designed for seniors with dementia living in long-term care facilities. *Dynamorph* aims to help users minimize boredom, reduce agitation, generate connectedness and make a positive impact with minimal involvement of the nurses, by providing the right amount of stimulations and meaningful activities.

2 Montessori Method

The Montessori method was originally developed by Maria Montessori while working with mentally challenged children [15]. Later on, this educational method has been widely adopted to teach cognitive, social and functional skills to children. It breaks down tasks into steps from simple to complex, from concrete to abstract, making students move only a little beyond their comfort zone whilst preserving the ability to improve. The same principle was later applied to persons with dementia by Camp [16] and showed that Montessori activities are well suited for dementia groups as well.

Dynamorph utilizes the Montessori method for designing activities that suit personal profiles of residents with dementia. For instance, puzzling is identified as a common activity for residents with dementia in nursing homes. However, due to the decline of their cognitive functions, seniors often face frustration caused by not succeeding in completing the puzzle. Therefore, puzzling showed to have few positive effects. We argue that Montessori method, instead, can better offer activities that reflect the individuals' interests and skill levels [17], because it is based on levelled framework that breaks the interaction into steps and processes that range from simple to complex, and from concrete to abstract. Seniors can freely explore and the caregivers can control the interaction levels in order to fit different users' conditions and a range of needs.

3 Design of *Dynamorph*

3.1 Concept

Adopting essential elements from the Montessori educational method such as self-exploration, task break down, rewarding system, tangible interactions [16, 18, 19], *Dynamorph* was designed to provide meaningful activities suited for the personal conditions of the seniors. In addition, the table was designed to fit the daily routines of the seniors, requiring only minimal involvement of nurses. Following an iterative design process, caregivers and residents with dementia were involved within the development of *Dynamorph*, a table with multi-layered interactive interfaces (Fig. 1).

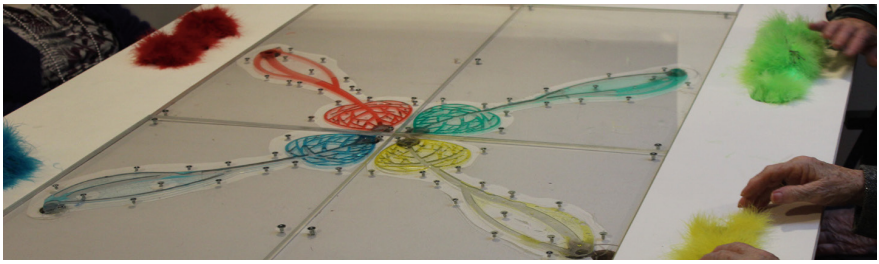

Fig. 1. The final prototype of the *Dynamorph*.

The tangible interfaces are composed of two basic elements: four zoomorphic shapes on each sitting place of the table and four leaf-like shapes pointing to the centre of the table. The zoomorphic shapes are made of attractive, vibrant coloured goose down with a soft sponge core consisting of ball sets inside. The size of the core is designed to ensure comfortable grasping so that the seniors can squeeze and hold these artefacts, and the down offers cheerful appearance, invites touch, and adds some animal fur feeling to it. Each zoomorphic shape consists of three individual balls mounted on different motors that visually appear like a single entity and are programmed to mimic several animal-like movements (Fig. 2(a)). For example, if all three balls slowly move up and down in different directions, they appear alive, pulsing and breathing. The illusion of a single entity suggests a natural and animal-like character.

Each organic leaf shape was made with transparent acrylic-based resin plate. The leaves were milled to be hollow so that they could be filled up with coloured liquid originating from each ball set, forming together as a connected pattern. If a senior interacts with a zoomorphic shape this will be detected by conductive wires hidden in the balls. The heart rate sensors installed besides the ball set on the table would pick up the signals detected from the wrists of the user, then transformed into dynamic leaf-shaped patterns filled by coloured liquid with the rhythm of the heartbeat, shown on the transparent surface of the table centre (Fig. 2(b)).

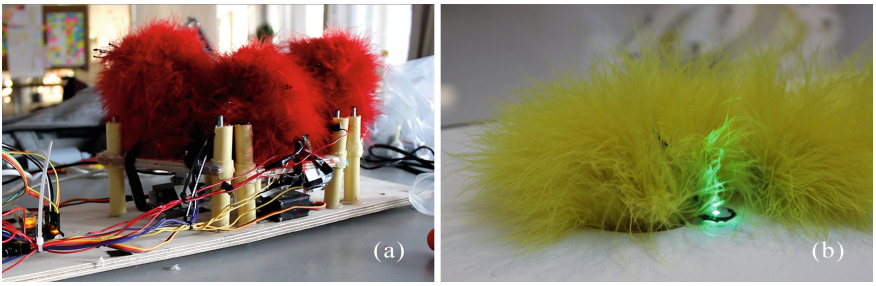

Fig. 2. The design details of *Dynamorph*. (a) Zoomorphic shapes consisting of three separate balls are mounted individually on mechanisms underneath the table to be programmed to respond correspondingly to user's gestures. (b) A zoomorphic shape powered by the interactive ball set with a pulse sensor embedded in the table.

3.2 Four-Layer Interaction Design Inspired by Montessori Method

Four-layer interaction structure was designed to alleviate boredom, bring connectedness and further generate positive effects. Each layer has a specific meaning and embodies a hypothesis for potentially positive effects on the seniors with dementia.

In the first layer, interaction between individual and the zoomorphic object that pops out from the table takes place. The zoomorphic objects consist of sets of 3 balls that can be sensed under the feathers. This choice was made because related research indicated that the ball-shaped object is appealing to dementia patients with all levels of cognitive impairment [14]. The interactive ball sets were stitched with conductive wires then programmed to be able to sense the contact and force with which they are handled to distinguish different gestures. The reactions to different inputs are designed to perform as natural as possible and to adapt to the interacting person [20].

With the aim to provoke reactions from the senior person, one of the balls embedded in the zoomorphic shape starts popping out of table every 10 min, then dives back and pops up again with a higher altitude than before. Letting the ball dive faster than it rises creates a curious and bashful character. If this movement is ignored, the ball will slowly go back to the table through a hole and the zoomorphic shape will appear like a sad animal that did not get any attention. Then, 10 min later, another ball will come up and start a new loop of interaction. During the process, if the zoomorphic shape gets gently touched, held or petted, it will start to mimic the breathing pattern of an animal in order to give users a feeling of a pet. If it gets hit or slapped, the 'hurt' zoomorphic shape will hide in the table with a relatively high speed to show rejection towards user's behaviour. The attractiveness, designed movement and generated interactions of the zoomorphic shape form the first layer of interaction of *Dynamorph*.

The second layer aims to promote interaction between the individual and the leaf-shaped interface. Inspired by organic shapes, the pattern in the centre of the table was designed to be symmetrical and have aesthetic attributes. The pattern is normally transparent and therefore barely visible. It will appear in colour only when there is a continuous positive interaction with the corresponding zoomorphic shape, by filling up with coloured liquid in synchrony with the users' heartbeat signals. This behaviour was

designed with the intention to give the user a sense of self-identity, as the self-identity stimulation is related to significantly higher levels of pleasure than other control stimulation within advanced stage dementia [12]. The use of liquid and organic shapes is also intended to have a calming effect, in order to ease agitated behaviours and enhance the positive engagement.

The third layer contains interactions among different modularized designs, which are intended to have an impact on self-awareness of the individual users [21]. Each ball set and the connected leaf-shaped pattern with liquid in its route were designed using cohesive colour choice with high contrast to enhance the attractiveness, keeps users' attention and give them a personal playing role as well [22]. It helps build a logic connection between the interactive ball sets and the patterns filled up with same coloured liquid. The liquid, instead of projection or lighting, is adopted in addition to a sound effect, as pumping with the heartbeat may sound like a rhythm and help users better recognize the feedback [23]. This modularized design aims to stimulate the self-awareness, and gives the seniors possibilities to make comparisons, so they are in charge of their own autonomy in controlling one set of the elements. Further fulfilling their need of controlling and possessing their own things, and may even generate the feeling of connectedness between nearby users.

The fourth layer attempts to stimulate interaction within the user group. When multiple users interacting with the ball sets trigger the corresponding liquid pumps, the centre area of the table will morph into a pattern with symmetric leaf shapes and different colours that are designed to be attractive. Creating the attractive pattern together would incur a sense of connectedness within the group. These four layers of interactions together form the four-layer interaction framework of *Dynamorph* (Fig. 3).

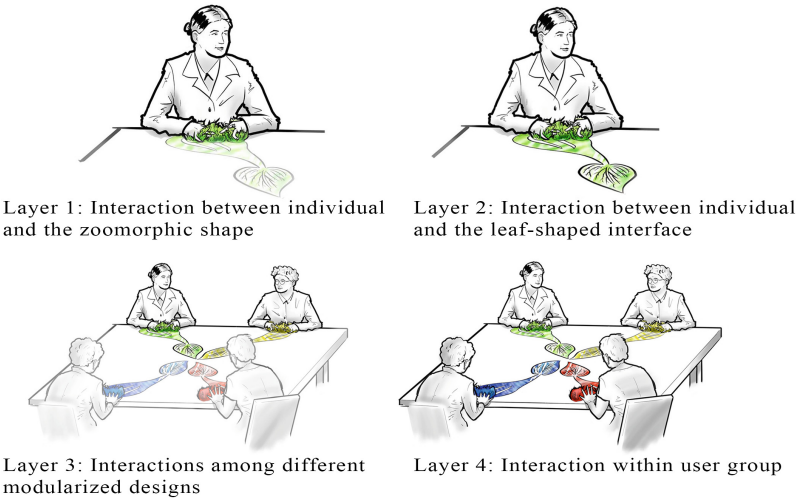

Fig. 3. Illustration of the four-layer interaction framework of *Dynamorph*.

4 Evaluation

4.1 Participants

Participants were recruited from Vitalis (KleinschaligWonen), Eindhoven, the Netherlands, an elderly care home that focuses on formal care for seniors with various forms and stages of dementia. The evaluation was conducted with four participants and one nurse for her expert feedback. The participants were all female, Dutch, with the average age of 85, ranging from 75 to 93. All the participants had the formal diagnosis of dementia and with different levels of cognitive decline according to the altered four-stage Clinical Dementia Rating Scale used in Vitalis. All participants are female due to the majority of residents being females (38 out of 40). Participants with a functioning level of auditory and visual abilities were selected. Participant demographics are presented in Table 1.

Table 1. Participant demographics.

Participant	Gender	Age	Stage	Form of dementia	Marriage status
P1	Female	75	2	Vascular dementia	Widowed
P2	Female	84	2–3	Vascular dementia	Married
P3	Female	88	2–3	Vascular dementia	Widowed
P4	Female	93	3	Vascular dementia	Widowed

4.2 Procedure

The evaluation was approved by Vitalis in advance and informed consent was obtained from legal guardians of participants. The prototype was placed in the living room of a small community of 7 residents with dementia. Four participants were invited and then seated for up to 90 min. They were told the purpose of the evaluation and were encouraged to explore the table by themselves. A nurse was present to accompany and observe the participants. After that a semi-structured interview was held to acquire expert opinions from the nurse. The evaluation was documented using video cameras and audio was recorded using cellphones. The audio recording was transcribed into text and then translated into English for qualitative data analysis. With inter-rater agreement, the qualitative data were analyzed by two coders, coding independently using the online platform Dedoose[1].

5 Results

Seventy six quotes were selected from the transcript. The selection was limited due to the language impairment of some participants. The selected quotes described their attitude towards the design and the interaction during the evaluation process. Resulting

[1] Online Dedoose platform for qualitative data analysis, www.dedoose.com.

from the process of collaborative coding, six categories of discussion themes emerged, as an indication of their focused interest points with subcategories and each subcategory with an exemplar quote, shown in Table 2.

Table 2. Categorization of discussion themes resulted from qualitative analysis, sub-categories, exemplars and number of quotes in each category/subcategories, the categories also reflect relationships correspond to four-layer interaction framework of *Dynamorph*.

Category of discussion themes	Correspond to interaction framework of *Dynamorph*	Sub-category	Exemplar quote
Interactive ball sets (43)	Layer 1	Aliveness (29)	"Look at this, it becomes alive. Look at this. Hello? (to the ball)" (P3)
		Aesthetics (14)	"Beautiful, wonderful, yes! That's very beautiful isn't it?" (P3)
Leaf-shaped pattern (7)	Layer 2	Leaf shapes (3)	"This is very beautiful (pointing to the leaf shape)." (P1)
		'River' (4)	"They are all swimming (referring to the colour liquid). It went all to this (draining by the outfall)." (P4)
Reflection of self-identity (8)	Layer 3	'My, mine' (5)	"Mine is moving, mine is alive. This one is working, and this one is not working anymore." (P3)
		Projection of one's heartbeat (3)	"It does only work for you, not for me, how is that possible? I don't have enough heart beat." (P1)
Social inclusion (9)	Layer 4	Forming a conversation (6)	"Don't you like it? (asking P2), there are beautiful things attached. Don't you think it's beautiful? (asking P2)" (P3)
		Instructing others (3)	"See? You play it like this, you can touch it (instructing P4)." (P3)
Emotion status (7)	–	Positive emotion feedback (5)	"It's cozy, we are cozy. I haven't had this for years." (P2)
		Making jokes (2)	"There might be a little guy in it." (P3)
Others (2)	–	Sharing past experience (1)	"This is beautiful. It is nice if you sew it somewhere else. I always sew, but nothing like this." (P1)
		Counting movements (1)	"Step, step, step. One, two, three …" (P4)

During the evaluation, participants showed great interests toward the zoomorphic object that consisted of feather ball sets. The seniors interacted with those on own initiative and without any instruction. This shows that the concept worked quite well as an occupational engagement tool. Discussions around the interactive ball sets about the aliveness and aesthetics emerged and made up the majority of conversations (43 out of 76 quotes). The aliveness was a crucial incentive for the users to take the initiatives (29 out of 43 quotes), and the responsive behaviour made them want to interact with the object even more. They were all able to recognize the zoomorphic shape as a living object, referring to it as an animal or pet, P3 even named the ball set in front of her as "Peter" and said "Goodbye, my friend" to it when left. The high colour contrast and the texture also provoked their initiatives, as the users found the colours enjoyable and vibrant. The goose down texture reminded them of the furry animals, which triggered them to pet it. There was a positive effect on the social inclusion, as the interaction caused many conversations among the seniors. For instance, P3 who had relatively high level of language ability expressed herself more frequently than others, helping other participants interact with the zoomorphic shape, as "See, you play it like this, you can touch it". The participants enjoyed the process and showed positive emotions on several occasions when interacting with *Dynamorph*. They laughed, made jokes about the design, and expressed their feeling through words. Participants with all levels of cognitive impairment were engaged well with *Dynamorph*.

The in-depth interview with the nurse confirmed the autonomous attraction of the seniors with dementia and acknowledged that this provided the seniors with dementia meaningful activity for occupation when the nurses are unable to pay attention to the seniors. Petting the object and being amazed by its movements, colours and texture kept the seniors with dementia busy, calm and avoided the situation that they started looking for confrontation with each other or engage in negative activities. The nurse emphasized the calming and positive effect *Dynamorph* brought to the seniors as: "There are people sitting there (points to table) petting for over 40 min. So you are already giving them a form of inner peace otherwise they wouldn't sit down for that long time". The peace and harmony that was rarely present were evident when interacting with *Dynamorph*. These all confirmed the effects on users' positive affection, and further on their quality of life.

6 Conclusion and Future Work

Dynamorph was presented with the intention of providing meaningful engagement and levelled stimulations based on the conditions of senior residents with dementia in long-term care facilities. A four-layer interaction design inspired by the Montessori method was proposed. The prototype was then evaluated, using a qualitative research approach for data analysis. The result of the evaluation indicated that *Dynamorph* was able to bring calmness among users, which would lead to reduced agitation, moreover helping to form communication and positive social behaviours [24]. The calmness and harmony during the evaluation, and the balance between interaction and social inclusion also proved that layered interactions worked for the target user group.

Evaluation also brought useful insights that can provide guidance for future developments of this design and inspire similar developments. For instance, the users had difficulties building a logical link between the zoomorphic ball sets and the patterns that are filled with liquid. Therefore future improvement of the design should aim to increase the intuitiveness and establish a connection that is easier to understand than it is now. Furthermore, for the validation of the framework and the design, controlled long-term studies with more participants are needed for fully investigating the effectiveness of this design. Due to the limitation of the verbal language abilities of the seniors with dementia, further analysis should also consider analysis based on non-verbal signals such as facial expressions, gestures and movements [25].

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