Prototype Development of a Responsive Emotive Sensing System (DRESS) to aid older persons with dementia to dress independently

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Background Prior research has critiqued the lack of attention to the stressors associated with dementia related dressing issues, stigmatizing patient clothing, and wearable technology challenges. This paper describes the conceptual development and feasibility testing of an innovative 'smart dresser' context aware affective system (DRESS) to enable dressing by people with moderate memory loss through individualized audio and visual task prompting in real time. **Methods** Mixed method feasibility study involving qualitative focus groups with 25 Alzheimer's family caregivers experiencing dressing difficulties to iteratively inform system design and a quantitative usability trial with 10 healthy subjects in a controlled laboratory setting to assess validity of technical operations. **Results** Caregivers voiced the need for tangible dressing assistance to reduce their frustration from time spent in repetitive cueing and power struggles over dressing. They contributed 6 changes that influenced the prototype development, most notably adding a dresser top iPad to mimic a familiar 'TV screen' for the audio and visual cueing. DRESS demonstrated promising overall functionality, however the validity of identification of dressing status ranged from 0% for the correct pants dressing to 100% for all shirts dressing scenarios. Adjustments were made to the detection components of the system raising the accuracy of detection of all acted dressing scenarios for pants from 50% to 82%. **Conclusions** Findings demonstrate family caregiver acceptability of the proposed system, the successful interoperability of the built system's components, and the system's ability to interpret correct and incorrect dressing actions in controlled laboratory simulations. Future research will advance the system to the alpha stage and subsequent testing with end users in real world settings.

Keywords: Housing and daily activities, smart dresser, gerontechnology

Eighty percent of care provided at home is delivered by family caregivers who on average are aged 55 or older and live in the same household as the person for whom they provide care[1]. More than 60% of family caregivers report high levels of stress and 33% report symptoms of depression because of the physical and emotional demands of caregiving[2]. Alzheimer's disease (AD) caregivers' exhibit greater morbidity and higher mortality rates when compared to non-Alzheimer's caregivers[3]. Data indicates the majority of these caregivers (86%) help with the activities of daily living (ADLs) most commonly dressing (61%), feeding (52%), bathing (37%), toileting (34%), and incontinence care (26%)[4]. In the late early through middle stages of dementia, caregivers report that dressing is their most pressing daily concern and it is especially difficult for adult children who have to dress a parent[5,6]. Forty percent of caregivers assist with dressing for at least 14 hours per week at a contributed economic value of $2.16 billion U.S. dollars[7]. Almost one third of these caregivers reported helping with dressing for more than five years.

As dementia advances and inhibits the self-care abilities of persons with dementia (PWD), the multiple daily tasks of dressing and undressing become increasingly difficult and a major stressor for both PWD and caregivers. Disputes can arise when there are differences in opinion regarding preferences in clothing items and/or the need to dress. Tensions can escalate from time pressures due to a health care appointment or other scheduled activity such as day care. There are suggested guidelines for dressing PWD, but caregivers must find, memorize, and consistently apply the recommended strategies to minimize frustrations with dressing[8]. Direct aids to help caregivers manage dressing problems also are limited. Alzheimer's caregivers complain that commercially available dressing aids such as button-hooks and stocking pull-ons are designed for persons with physical disabilities and are too complex and confusing to those with dementia[9].

Prior research has critiqued the lack of attention to the stressors associated with dementia related dressing issues[10], stigmatizing patient clothing[11] and wearable technology challenges[12]. Others suggest the need for persuasive gerontechnology initiatives[13]. The current state of the art in cognitive assistive technologies has been to use machine learning techniques to mathematically attempt to predict patterns of behavior using sensing devices, but frequently the results have been critiqued as disappointing, not relevant or meaningful to PWD[14-23]. For example, the COACH system was developed to use computer mediated input from sensors on and around a bathroom sink to transmit through the bathroom mirror above it verbal coaching on proper hand washing steps[18,19]. While hand washing is not among caregivers' dementia related pressing problems, it is a safe limited step task that enabled COACH to demonstrate proof of concept and negate concerns that PWD would be unable to follow cueing or that voices coming from a mirror would increase their confusion. Researchers note the especially difficult challenge to develop interventions that can assess and adapt to PWD varying levels of cognitive functioning that occur over a course of a day, change by the week, and progressively decline over time at differing rates[16,23]. Thus there is a critical need to develop a new type of dressing intervention one that is designed to meet the dressing challenges specifically associated with late early through mid-middle stage dementia caregiving. Moreover, a dyadic intervention is most desirable, one that can both reduce the demands on the caregiver to be the sole source of dressing guidance and is able to respond to the fluctuating abilities of PWD.

Theoretical framework

Lawton and Nahemow's theory of person-environmental fit from their Environmental Press Model provides the conceptual framework for this study[24]. Fit refers to the balance between persons' competence and the press from their environment. With cognitive impairment there is a mismatch between a person's abilities and the demands exerted by the environment thereby creating individual lag. Lawton challenged gerontologists and technologists in the field of Gerontechnology to address this lag with supportive or prosthetic means of fortifying fading function[25]. We envisioned the environmental demand occurring from the sequencing and task requirements for dressing as a major source of cognitive overload for a person with dementia, one that significantly contributes to his or her lag.

Context-aware affective computing detects and interprets the emotional state of humans (affect) through facial, posture, voice analysis and/or physiological monitoring and aims to respond appropriately to their emotions. It offers a new method of responding to lag and adapting to the specific user's situation (context) and needs through sensing devices imbedded in home and in personal devices that process inputs and support activities[26]. An example of an affective computing device is a wrist watch like bracelet with an imbedded sensor for wireless galvanic skin conductance sensing (similar to the lie detectors process) to detect stress from autonomic system arousal[26]. Arousal results in increased sweat gland activity which then increases skin conductance enough that it can be measured electrically. This technology has been used to develop an interactive learning companion for helping learning disabled children convert their 'stuck' or non-optimal experiences to 'flow'- optimal task performance as well as with autistic children[27-32]. Literature reviews cite numerous articles on the potential of affective computing, especially with gaming and robotics, but there are no direct care applications for older adults who cannot turn on and actively manage technology devices[33-36]. However, we noted that similarities exist with PWD who become 'stuck' or off task during dressing from cognitive overload that triggers stress and eventual task breakdown. This raises the possibility that similar affective technology could sense PWD rising stress levels and adapt task guidance to foster task accomplishment.

The purpose of this study was to address the following key research questions: (i) How will family caregivers' respond to the proposed smart dresser idea (DRESS) and what design improvements would they recommend? (ii) Is it possible to build an interoperable system capable of correctly identifying and guiding complex dressing actions in real time?

Concept design and technology

We undertook the Development of a Responsive Emotive Sensing System (DRESS) to address the Alzheimer's disease induced lag in dressing activity by providing cognitive assistive support through an inter-play of technologies that innovatively tailored the motivational counseling to the emotive responsiveness of the person with dementia. From a technical perspective the DRESS system consists of an integrated constellation of sensors and user interfaces that are readily configured to be contextually aware of PWD and caregiver's activities and elements of their affective states. The initial system user interface design was based on Mahoney's gerontological nursing experiences in response to family caregivers request for assistance with dressing and lessons learned from her prior gerontechnology intervention projects using interactive computer mediated caregiver assistance. Burleson's experience with affective technology development and his existing Game as Life-Life as Game (GaL-LaG) [37] platform facilitated interoperability with the variety of technologies, databases, and interactive software scripting necessary to support the technology operations for DRESS.

DRESS's design objectives are to minimize the technology burden on users by eliminating demands on caregivers for system installation, power requirements (e.g. batteries), daily check-ins, data transmissions and other maintenance. We incorporated an iterative user-centered design approach with participatory involvement from caregiver teams and family members to critique to our preliminary design and suggest recommendations for improvement to better meet their needs. The input from caregivers' preferences was planned to drive the final composition of technology choices. From our previous experiences, we recognize that caregivers need to see model pictures and/or mock-ups of any new technology to help them better understand it and provide more informative feedback. We provided our caregiver sample with pictures of the DRESS system retrofitted on a dresser, the design template, and sample galvanic sensor wearable bands to accompany our discussion of the technology in our focus groups.

The original plans called for an ordinary 5 drawer wooden bureau to be retrofitted with the DRESS system in anticipation of using the existing home dresser strategically to avoid adding an unfamiliar object in the home. Each drawer would have contact and motion sensors to identify drawer opening, movement within, and closing.

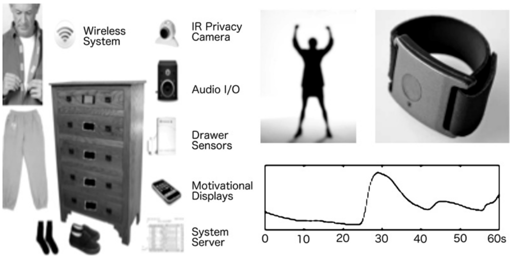

Figure 1. Proposed system components as shown to participants. Dresser instrumentation on left, privacy camera view in middle, wearable 'upset' sensor top right with data display below. © Mahoney & Burleson

A smartphone would be attached to each drawer to display a green light to attract attention to the appropriate drawer, a red light to indicate the incorrect drawer opening, and as needed, guide the users' dressing through voice prompting along with a picture of the correct clothing item. The user would wear a small skin conductivity sensor embedded in a wrist or leg band to transmit skin conductivity responses that relate to his or her state of emotional frustration (*Figure 1*).

At the user level, the caregiver would bring the PWD, wearing the DRESS wrist/leg band, to stand in front of the dresser. The system would be designed so that the caregiver only has to turn it on, once the default settings are recorded during the installation process. Following the Alzheimer's Association's dressing guidelines for logical ordering and simplification of clothing choices, clothing would be separated by drawers to present the clothes in the order to which the PWD is accustomed[8]. In our sample example, the top (drawer #1) IPod initially lights green to signal attention to start at this drawer containing underpants/briefs. The light remains while there is activity within and will shut off upon task completion as determined by lack of motion from the constellation of sensor inputs. This represents a low power load on the device. Next the undershirt/bra drawer (#2) will light followed in turn by the drawers for the pant /slack (#3) shirt (#4) and socks (#5). If the PWD becomes 'stuck' (a non-optimal experience), then motivational prompting through the smart phone will be used to engage the PWD and convert nonproductive actions toward a more optimal state, e.g., toward 'flow'. The system would continually monitor the end user's stress response via the skin sensor and adjust guidance to reduce rising frustration levels. Should the PWD's stress level continue to increase, the system initiates an activity previously deemed by the caregiver as soothing, such as a favorite song or video clip. If the stress level still does not decrease, the system then notifies the caregiver via her/his choice of communication i.e. cell phone/text messaging or the caregiver's

IPod set-up / alert device, before the 'meltdown' threshold is reached. If the dressing proceeds without distress, then the system would send a message informing the caregiver when dressing was completed.

Methods

To address the research questions, an integrated mixed method design was chosen because this best supports a formative iterative approach wherein the analysis of each phase leads to insights that affect the subsequent phase[38]. The field of gerontechnology recognizes that an effective way to attend to the human computer interaction challenges of ubiquitous computing systems, to ensure a good 'technology fit', is by involving end-users throughout the design and usability testing phases[39-41]. This approach enables developers to improve the prototyping process and interface of a product using data obtained from user interactions; ideally it is recommended that this process occur with each stage of major development (conceptual, alpha, beta, and product release)[42]. Before initiating the research, the study protocol, including both the qualitative and quantitative sub-studies, was approved by the Institutional Review Boards for the Protection of Human Subjects at both participating academic institutions as well as the Massachusetts Executive Office of Elder Affairs.

Q1. Caregivers' response to the proposed DRESS system and recommendations.

The present study, being at the conceptual phase, commenced with a qualitative inquiry in order to better understand the caregiving issues that would guide the technology development phases. The numerous dressing and interpersonal challenges experienced in family caregiving as well as extensive details on the qualitative methodology have been reported previously[9]. This paper uniquely reports the caregivers' reactions to the proposed technology and their recommendations to improve usability for PWD.

Participants

Primary family caregivers of PWD, who had difficulty dressing without assistance for at least six months, were recruited in Boston over a six month period during 2011. Sources of referrals were the Massachusetts General Hospital's Volunteer Research Registry, Partners' Alzheimer's disease research center's clinics, participants' referrals, and two senior housing residences. Twenty-nine respondents contacted us and were screened for eligibility over the telephone. Four were found ineligible due to lack of dressing experiences. The remaining 25 family caregivers consented and completed the qualitative study phase.

Procedures

Three focus groups were conducted comprised of on average 6 caregivers clustered by locale and available time in common. In addition, individual telephone interviews were held with 7 participants who could not match with any locale and/ or leave the PWD. We did provide study staff support for PWD to enable attendance but the majority of participants declined. Four caregivers did bring their family members and in each of these cases it was because the PWD became extremely upset when the caregiver went out without them. Each group was asked to review and critique DRESS using the 'think out loud' format to respond to the model presentation and proposed operations[42]. Participants were shown the pictures in *Figure 1*. First the dresser bureau and instrumentation were described. They also were shown a mock wearable sensor to gain their impressions about whether it should be worn on the wrist or ankle for best acceptance. And the privacy aspects were discussed and queried if adequately addressed by using a camera set to only show a shadow image (*Figure 1*).

After discussing the key technology components, members were asked to think about their own dressing routines and to walk through the system usage in their mind to identify potential problems or concerns. The sessions were all conducted by the same facilitator (DM) who used a semi-structured guideline to ensure consistency of exploration about the system's applicability, acceptability, and usability. The technology discussion started with general impressions of the system and funneled down to specific probes concerning the wording of the prompts, voice preferences, drawer organizing routines, and strategies to optimize completion of dressing tasks. A second attendant took field notes and participated in the analysis. All sessions were audio taped, transcribed, and verified. A content analysis was conducted of the transcripts with the responses read line by line and coded into themes with particular attention to positive and negative responses to the system's proposed features and operations. The sessions culminated in 'saturation', a qualitative hallmark of data completion that occurs when redundancy is attained. The interpretations followed standard qualitative procedures and were validated by telephone participants for confirmability and by sample group members to ensure trustworthiness of the findings[43,44].

Results

The twenty-five focus group participants were predominantly adult children (72%), female (68%), white (88%), and mainly provided direct help with dressing (76%) or supervision with cueing (24%). They were on average 63 years of age with the youngest age 39 and the oldest at 83. All of respondents had provided coaching to their family member to get dressed and undressed for an average of 45 minutes per episode for a three-year period. One of the wives described her typical assistance:

He tries to put his underpants on sideways, he tries to put them on backwards, upside down... I take them from him, I hold them up in the right direction, hand them to him. He turns them around, again. I take them back, I hand them to him, I stand there and I say, *"Put it on this way, this leg in this one, the other leg goes in the other one." He will try to put two pairs on. So that is pretty much the procedure with every article of clothing...he can get his jeans on most of the time... Socks he can do but often gets the heels in the front over the foot...he puts his jacket on backwards almost all the time. A lot of disasters going on over this dressing thing. A lot... It's just awful. (ID17, wife)*

Initially caregivers tried to protect the dignity of the PWD but over time dressing 'battles' became more frequent and tensions escalated.

She would get so annoyed with me...getting her dressed was insurmountable...I'd come over an hour and a half earlier than I was supposed to and many times she wouldn't let me in the room. "I can do this" she would say... but she couldn't...and then she would say "forget it, we're not going, it's too much" (and they would miss going to the family outing or dinner) (ID22, daughter)
[He was refusing to get dressed to go to adult day care and I said] if you don't do what I'm telling you to do like put your darn shoes on I'm going to have to put you in assisted living... then he stood out in the street and yelled - calling me a bitch and a horrible wife. (ID17, wife)

Participants cited the lack of dressing aids suitable for cognitively impaired. They were enthusiastic about the potential of DRESS to eliminate tedious repetition and irritable confrontations as well a means to facilitate preservation of function. They greatly valued the design, which enabled customized response in real time tailored to the user's state. This approach enabled withholding of coaching when the 'moments of lucidity' they all had experienced and treasured, did occur. Interestingly, none thought DRESS was violating personal privacy greater than usual care and it also offered potential benefits.

When I got a helper my mother thought she invaded her privacy ...[This wouldn't] (ID21, daughter)
There is a benefit I can see. Sometimes because of relationship baggage and stuff, it's like I'll do it for this thing, but I'm not doing it for him. If he tells me I'm going to get angry, but if this thing tells me I'll be okay, I'm still independent. (ID11, daughter)
Maybe it can help them stay calmer because they're reassured constantly (ID1, son)
At a stage where the person is still independent this can actually empower them to do dressing! (ID8, daughter)
I had ordered from some website a bed alarm that would tell me when he left his bed. And the alarm would startle the hell out of him and me… Something that could have transmitted to me in the room upstairs that he was active and I needed to check on him would have been absolutely fabulous. (ID18, daughter)

The caregivers, however, critiqued the cell phones on the lower drawers as unreadable and worried they would further confuse the user. As an alternative they suggested placing an iPad on top of the dresser to mimic a TV, a familiar source of audio and video stimuli.

With her eye problems I'm not sure she'd see any of that [iPhone]...she does watch a 17 inch TV. (ID 19, son)

Also they suggested the need to attract and maintain attention on the correct dresser drawer.

Perhaps you could have LED knobs on the dresser that flash to get his attention (ID25, son-in-law)

As a result we incorporated iPods attached in the center of each drawer as a simple, technologically flexible and visible solution to attract attention to the correct drawer to open. When the audio cue from the iPad on top of the dresser signals the directive to 'open the drawer with the green light', the IPod screen from the respective drawer would illuminate green and turn off only after the clothing item was removed. Additionally, if an incorrect drawer is opened, the iPod screen would illuminate red facilitating the identification of the drawer to close in order to open the correct one.

Some participants requested a mirror attached to the side of the dresser to encourage the user to check to see if the clothes were on correctly. Others requested a chair next to the dresser for putting on pants, shoes and socks with audio instructions to be included on how to sit down safely on it. We added both. Caregivers did not see the need to include underpants/briefs in the sitting segment because most toileted their family member upon rising and many put on an adult diaper and over-brief before leaving the bathroom to get dressed. This prompted us to create multiple dressing modules that could be flexibly arranged according to the user's typical dressing pattern, rather than assuming undergarments came first.

If there were simple instructions, especially if they could sequence when she was ready for the next step...as opposed to assuming her actions [our reply yes]...That's brilliant! (ID3, daughter)
A menu that you personalize makes very good sense. You choose a soothing activity... music of the era, maybe Frank Sinatra, Tony Bennet; I tired family photo albums to distract him but it was a huge flop... (ID18, daughter)

Caregivers differed on whether to use the family caregivers' or 'our' voice for the audio coaching and we thus decided to offer both options.

She (mom) trusts me...She needs my voice for prompting; I don't want to upset the applecart! (ID21, daughter)
No, I don't want my voice used; it would only irritate him more. (ID17, wife)

We also queried about their preferences for the type and location of the wearable sensor for best acceptability by their family member. They preferred the wristband to a leg band or waistband.

Make the wristband look like a watch, have a watch like face, be waterproof, and hard to get off! (ID19, son)

The majority (80%) used a 5 or 6 drawer dresser / bureau; the others laid out one set of clothes on a chair or hung them in front of the closet. No one used a closet or armoire because by this stage it was too confusing and distracting. They validated the DRESS design as non-intrusive and workable in their homes because it retrofitted to their furniture.

She gets lost in her closet...it's too overwhelming now. (ID3, daughter)
There would be no place in her room to introduce another piece of furniture [or equipment] (ID21, daughter)
This could work well as part of the furniture! (ID19, son)

Those not using a dresser (20%) felt they would be motivated to convert to using this system if it also monitored for falls and wandering in and out of the dressing room. We adjusted the design to include monitoring for wandering and fall alerts, although we have not explicitly tested the accuracy of these features yet.

She forgets when she falls...forgets to push the [personal emergency] help button or tells their voice she is ok! (ID21, daughter)
Broaden the use of the wrist thing beyond just the dressing. If they're in the midst of dressing and they leave to go into the bathroom... prompt them back...if they wander away you can find them. (ID6, son-in-law)
You have no life as a caregiver, any little amount of the time is a gift…and to help the person with dementia to hold on and help them stay independent…this is great! (ID24, daughter)

A summary of the caregivers' key recommendations with our resulting technology adaptations is outlined in *Table 1*.

Would caregivers' use DRESS?
When asked if DRESS were available this year, twenty-two reported they would immediately volunteer to try it, two said they would wait and see how the experience went for others before trying it, and 1 caregiver declined noting a humanistic concern:

I can see some benefits helping someone to stay independent longer [and] giving the caregiver a break. What's bothering me is the impersonal nature of technology itself as a substitute for hands on care, personal care. (ID13, daughter caring for mother)

Besides willingness to use, willingness to pay for a new technology is another important adoption indicator. Concern about affordability was raised. While the majority of the interested caregivers would try DRESS if it was covered by insurance, two thirds of the participants reported that they were willing to self-pay up to $60 a month. The other third feared that if this system took longer than two years to deploy, their family member would no longer have the cognitive capacity to respond to any type of coaching.

Participants also forewarned us when we first test our system with caregivers and PWD to allow a prolonged period of time over several months for them to imbed the system as part of their daily habit. *As one said:*

"It's part of the training, you have to make a commitment to do this every day...You can't do it one day and not do it another day...that will really confuse them ...You have to get it in the daily routine." (ID12, wife)

Participants discussed the increasing use of monitoring technology in homes today. Several were managing biometric monitoring of their

Table 1. Caregivers' design themes, recommendations, revisions © Mahoney & Burleson

Theme	Recommendations	System revision
Promote normalcy	Use iPad for a dresser top 'TV' with iPods to light drawers; Use wristband "watch" rather than a leg band sensor holder	Added iPad on top of the dresser to show cues and verbalize prompting Changed iPhones to iPods for green/red lighting rectangles on drawers Adapted to wristband
Integrate usual routines	Include chair use and mirror check of appearance in dialog; Assume in the morning that briefs/underpants are already on	Added chair with pressure sensors to identify user sitting. Incorporated messages to check appearance Made briefs/underpants dressing module optional
Humanize	Provide an option to use the caregiver's voice; Offer a variety of cueing stimuli	Developed option for caregiver's voice and personalized messages. Integrated tailored messages, relaxation guidance and music favorites for calming activities and visual and verbal interactions for stimuli
Safety enhancement	Monitor and alert for falls and wandering out of the room	Added motion sensors to the room setup to identify wandering or no motion with prompting to the user and caregiver alerts
Flexible customization	Adapt to different dressing combinations and routines; Adapt to 5 or 6 drawer bureau dresser; Adapt to daily fluctuations in cognition	Incorporated options for clothing item selection, order of presentation, and number of dresser draws to be used. Selection of user's starting level of cognitive independence with real time adaptation of assistance based on user's responsiveness

family members' blood pressure and or glucose test results via telemedicine monitoring systems. Others used wellness monitoring on themselves to aid in exercise, weight loss, and fitness. They did not find the proposed DRESS system to be intrusive in their home or compromising privacy. They welcomed opportunities to use new technologies to help them meet their caregiving challenges. For example, a husband of one of the participants had converted their home security system into a wander monitor to make sure his mother-in- law with dementia did not escape at night. What these participants were concerned about was becoming overwhelmed by the variety, upkeep, and financial expenses associated with multi-technologies. One husband advised us that when this system is commercially released we:

Make sure this system can integrate with other home systems out there that watch your blood pressure and home safety so you don't have to buy multiple different systems as the disease progresses. (ID5, husband)

System feasibility

Conceptual stage development poses the question – Is the DRESS system technically possible and will it operate accurately? To ascertain the operational factors, initially a single drawer operational testing was conducted to support the basic proof of concept while the focus groups were being conducted. Subsequently the design was improved incorporating the highest priority caregiver recommendations and the five drawer version was built for the technical feasibility testing. This upgraded system included new features to enable caregivers to change the system's settings as desired and to facilitate more detailed PWD guidance.

The system automatically is initiated via simple tap on the system's iPod device, used by the caregiver (alternatively the system can be initiated by the caregiver on the iPad). This initiates the default settings designed to help PWD with the dressing process; these are based on the most standard needs and dressing procedures. However, the system also allows the caregivers to change the default settings to tailor the results and to enable them to receive updates on the current dressing status. Some of the features accessible from the iPod include (*Figure 2*):

(i) Set caregiver's information. This can be useful in a dialog like the following "[caregiver's name] is on the way to see you". The system also has the capability to record the caregiver's voice and use these to provide the messages to the PWD user. This serves to provide a more comfortable experience in cases where PWDs prefer a more familiar voice.

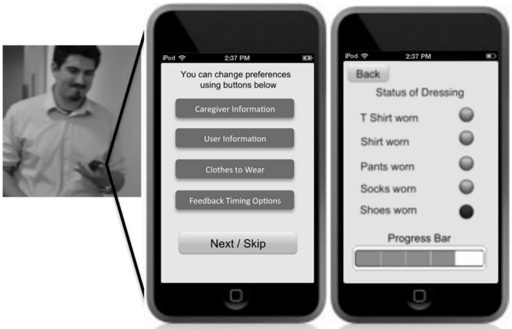

Figure 2. Caregiver system's interface. Examples of 2 iPod screens with system settings menu (bottom left) and status of dressing progress (bottom right). © Mahoney & Burleson

(ii) Set user's (PWD) information. PWD's name and gender can allow the system to adapt the type of clothing pictures to present as a reference, the caregiver can select the gender of the voice used to guide the user and the system can use the user's name. Selection of preferred soothing procedures like use of phrases or melodies for the user to be used when he or she gets disturbed by the dressing process can also be updated directly in the computer system. (iii) Set clothes to wear. Allows for clothing items and order to be set so that the user is prompted in the most comfortable sequence and only for the clothes that will be worn at that specific time. (iv) Set feedback timing. Based on the level of PWD lucidity at the time of dressing observed by the caregiver, the system can be set to start at a higher or lower frequency of interventions to more fluently match the needs of the user. Note that the system still has the capability to automatically adjust as necessary based on the detected dressing performance. (v) Track dressing progress. The caregiver has the ability to see the progress of the dressing process at any time via an iPod that comes with the system. This information can help the caregiver make plans either for intervention or for their own personal activities.

Based on the needs for the PWD user, the system was also enhanced by incorporating recommendations from the focus groups (*Table 1*). The current system has the following elements (*Figure 3*):
(i)iPad on top of the dresser. Used to provide guidance through images, and short written and spoken messages. Videos of how to put the clothing on are also a possibility to be shown in the device. (ii) Microsoft Kinect™ in front of the user. Used to identify user's dressing actions through tracking skeletal movement (e.g., lifting leg/arm, sitting, standing) in order to provide adequate guidance or corrections. Kinect is placed to the side of the system, in a secure and unobtrusive manner so as to view the user in their natural postural positions and actions, without encumbering the user. It has the ability to track the movement of the user in the field of view allowing to track among others: arm movements, leg movements, and if the person is sitting or standing. (iii) Fiducial tracking system (markers on strategic parts of clothing and camera on the dresser facing the PWD). The coding of each marker is used to determine what part of the clothing item is facing the dresser to identify if it is correct (e.g., front of the pants) or incorrect (e.g., inside of the pants). Combining skeletal and fiducial tracking allows the system to identify the status of the clothing worn and to give respective corrective feedback as necessary.
(iv) Radio frequency identification (RFID) tags on clothing and drawers. This is used to immediately trigger the initiation of the clothing guidance process when the tag embedded in the clothing gets farther from the receiver located inside of the drawer. Also, to prompt the user again to pick up the clothing item when there is a prolonged period between opening the drawer and removing the clothing.

System validity testing procedures
With this new version of the DRESS system we were interested in testing the ability of the system to correctly identify the dressing process, especially in common PWD incorrect dressing scenarios, e.g., for the two clothing items most commonly worn regardless of gender: pants and shirts. Because it is necessary to affirm that DRESS actually performs as intended before hav-

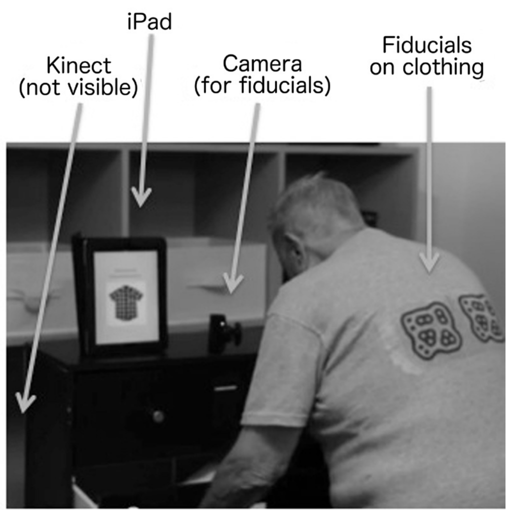

Figure 3. Revised system with recommended changes. New version of the system includes an iPad on top of the dresser, fiducial system including camera and markers on clothing, and Microsoft Kinect on the side to track skeletal movements. © Mahoney & Burleson

ing PWDs interact with the system, we conducted the quantitative technical operation validity trial with 10 consenting male healthy participants, ranging in age from 25-32, in a controlled laboratory setting. Four of the 10 participants were tested with only 2 pants scenarios, after adjustments were made to the system (see below).

The experiment lasted about 30 minutes per participant and consisted of performing 9 'acted dressing' sequence scenarios developed based on input from caregivers to simulate real-world in-home PWD experiences for a pair of pants (P) and a shirt (S) with Velcro under randomly ordered conditions of independent (system should withhold guidance), semi-independent (intermittent guidance required as necessary), and dependent (continual guidance required). Participants were first debriefed about PWD dressing challenges and then asked to follow a specific procedure for each of the dressing scenarios per clothing that included correct (pants-correct [P-C] and shirt-correct [S-C]) and incorrect dressing sets: back side in front (pants-backward [P-B] and shirt-backward [S-B]), pants/shirts inside out (P-I / S-I), partial one leg only pants (P-P) and partial one arm only shirt (S-P) and shirt having misaligned (S-M) Velcro. At the start of each sequence, the participant was informed about the condition (clothing item and dressing scenario) and was asked to open the drawer, take the clothing item out, put it on and then give the clothing item back to the experimenter. Additional instructions to maximize the identification process were given such as dressing slowly, standing in front of the dresser (camera) and holding the clothing item in front of the camera before putting it on. Although some of these constraints might not be ideal in the actual usage scenarios, we added these steps to ensure adequacy and consistency of data points for the comparative analysis of the scenarios to ascertain operational validity. After completing the corresponding dressing scenario, the experimenter then would collect the clothing item and put it back in the drawer for the next sequence. Clothing would be turned inside out before the trial in the P-I and S-I scenarios.

During the dressing process, when correct dressing was detected by the system, it would complement the user, saying "Good Job". When the system was able to detect a dressing error it would verbally state the error type and prompt the actions to rectify it. In situations in which the system was unable to detect the dressing error and the acted error had been completed (i.e., the participant stopped moving and began to wait for the next prompt) the experimenter intervened, prompting the participant to rectify the acted error so that they could proceed with the dressing activity.

Analysis and results

We measured accuracy of the system defined as the percentage of sequences it could correctly identify the dressing acted scenarios. To obtain this measure and find opportunities for system improvements, we performed the analysis with the following data: (i) skeletal tracking from the Microsoft Kinect, (ii) visible fiducial markers tracking of position and orientation, (iii) system's recorded trigger actions and dressing status detections, and (iv) video from a camera facing the participant.

Overall, with the initial participants, we found that the system was 78% accurate in detecting the nine acted dressing scenarios. Accuracy rates ranged from 0% for detection of wearing the pants correctly to 100% for detection of all of the shirt scenarios. Specifically, it was 86% accurate in detecting common dressing errors ranging from 33% for the most difficult inside out pant layout to 100% for shirts. Figure 4 shows the percentage of instances where the system correctly detected the dressing status and missed detections due to incorrect detection from Kinect or no detection from fiducial markers or Kinect.

In the case of the shirt dressing scenarios, the system was able to correctly identify the scenarios each time for all conditions (S-C, S-P, S-B, S-I, S-M). Similarly, when the pants were worn with the back in the front (P-B) it was also 100% accurate. Problems with detecting the fiducial markers were found for the pants inside out condition (4/6; 33% accuracy). This can be easily improved by increasing the number of markers or/and placing them in more visible parts of the pants (both of which the research team is currently advancing).

The most challenging scenario for the system was to track the pants when worn correctly (P-C), which was predominantly due to Kinect data issues.The Kinect also caused detection issues with the scenario where pants were worn partially (P-P). Note that these two had mostly the same clothing orientation and fiducial visualization. Problems with the Kinect data included incorrect detection (1/6 for P-P) and no detection of the user lifting legs to push into the pants (1/6 for P-P and 6/6 for P-C).

Further analysis of the errors made by the system revealed that the main reasons for this poor result were two fold. First, when participants held pants in front of them before putting them on, Kinect fails to detect the pants as an article of clothing

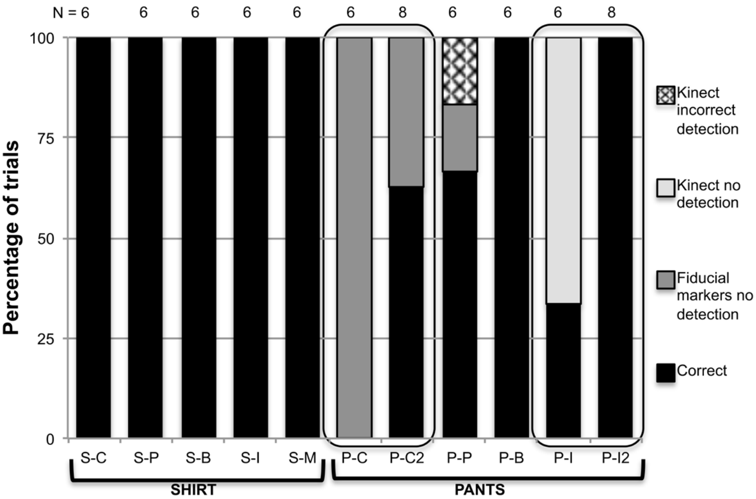

Figure 4. DRESS validity testing results. Percentage of trials correctly (green) and incorrectly (grey, red and orange) detected for the original (n=6 trials) and second (n=8) experiment after rectifying the system and re-testing two pants conditions (P-C2 and P-I2). Rectangular area for each of the additional testing shows improvements in system's detection. Top numbers indicate the number of trials. © Mahoney & Burleson

but rather sees them as part of the participant's body. Second, each participant wears pants differently. To detect leg lifting Kinect uses a threshold common to both legs. It was observed that all the participants lifted their right leg higher than their left leg while putting the pants on.

We adjusted the system based on our observations and ran further trials with 4 participants acting the pants correct scenario (P-C2) and inside out (P-I2) dressing scenario 2 times each (8 trials per condition), resulting in raised overall pant scenarios detection accuracy from 50% to 82%. With a differential Kinect threshold for each leg, detection of P-C increased from 0/6 to 5/8 times (Figure 4 left marked rectangular area). Although this is encouraging, it is still technically challenging to prevent the Kinect from detecting that the pants are part of the body when they are held in front of it without being worn. The P-I dressing scenario, where pants had additional fiducial markers, resulted in 100% (8/8 times) correct system detection (Figure 4 right marked rectangular area).

With respect to the prompting accuracy, we noticed potentially confusing messages in 2 situations: inside out message for shirt while in the process of correctly wearing it and partial pants message while the user was still in the process of completing the dressing. For the shirt, we noted that the inside markers were briefly visible by the camera in occasions like when the shirt is slightly folded showing the front inside part of the shirt or when transitioning to putting the second arm on. In these two scenarios, timing could be used to overcome these challenges.

Discussion

The first purpose of this study (Q1) was to elicit caregivers' impressions of the automated prompting system for dressing. Over the last five decades the media and social critics frequently suggest that the use of technology dehumanizes caregiving by attempting to replace human caregivers, increases elder isolation, violates personal privacy and ethical care[45,46]. Only one of our participants, however, expressed similar concerns. The vast majority of the participants differed and identified important personal benefits from the proposed technology that has not been publicized. Caregivers saw DRESS as an objective neutral intermediary that could buttress their negative emotional interactions that arose when either they and/or their family members were frustrated with dressing. They viewed the technology as offering the advantage of never becoming weary, tired, irritable, provoked or abusive[47]. With automated technology, a calm consistent response is given no matter how often or for how long prompting is needed. There was a desire among a few of the caregiver participants to use their own voice for more familiarity in the prompting dialogs. Others disagreed and felt their voice would only continue to provoke the power struggles over clothing disagreements and they preferred a neutral voice. Research based evidence to guide dialog development and understanding of differential responses to automated versus family vocal communications is lacking in the dementia literature and in need of future study.

Caregivers also exhibited a preference for promoting normalcy by using familiar objects and the design features of DRESS enabling it to retrofit the user's existing dresser was highly regarded. The theme of integrating usual routines supports normalcy and was achieved by tailoring the order and sequencing of dressing to an individual's pattern to stimulate procedural memory. The flexible customization components appealed to caregivers as a means to be responsive to their family members' routines and variable patterns of cognition. Prior research supports the need for multi-component offerings that integrate non-intrusively into everyday settings to promote adoption[48-49].

Caregivers positively responded to the introduction of a practical safe activity that provided cognitive stimulation. Caregivers felt this offered a respect for PWD and promoted dignity by enabling them, sustaining their independence and providing a sense of accomplishment. This aspect was not found in prior literature and is worthy of evaluating whether these perceptions are realized in the deployment phase. As others have noted, safety concerns can trump privacy issues[49,50]. Caregivers did not view privacy concerns as a barrier given the personal intimacy issues they faced in dressing, bathing, and toileting. DRESS was not transmitting pictures of personal body parts but skeletal movements and this was very acceptable. The addition of monitoring for wandering out of the room and falling was of high value, a positive factor supporting adoption. Caregivers were willing to tradeoff privacy for the safety benefits resulting from personal surveillance and alerts. This research suggests that thoughtful designs incorporating knowledge from the field of Gerontechnology, transdisciplinary (including ethics) research evidence, and the involvement of the older adult end users can foster humanistic approaches that are acceptable and even desirable to caregivers[51]. Further research must be done to ascertain the reactions of PWD.

Q2. The second area of research inquiry tested the technical feasibility and validity of the DRESS system. We have demonstrated that the combination of Kinect skeletal tracking and visual tracking of fiducial markers on the clothing can detect common dressing errors 83% of the time, which leads us to conclude that automated dressing support systems that employ this approach may be a viable option to assist PWD in dressing. Such a system may help them maintain independence and provide their caregivers respite, within the context of dressing behaviors in their homes. With some minor changes in experiment 2, we have shown that the recognition rate of the system to detect common dressing errors can be improved. There are several known challenges with the current system and it will require more efficient rule-based algorithms to solve them (see limitations section below); however the technology used in this system is already highly effective, interoperable, and is likely to provide the pre-requisite capabilities needed to advance greater levels of independence and well-being for PWD and their caregivers in the context of dressing. It provides effective verbal assistance in dressing, whenever it identifies errors in dressing, and helps in rectifying them by prompting the user with information on how to proceed with the dressing activity. Improving Kinect's ability to detect what action the user is performing will be a central element of our immediate future work, to improve the system prior to in-home deployment. It is to be noted that the data that is received from Kinect is important for the program to make a decision on whether the person has worn the pants partially or completely. Identifying the dressing pattern used by users when they wear pants can be useful in tailoring the Kinect program to be able to detect them efficiently. A more challenging task is to capture skeletal data accurately when the user is holding pants or any other clothing in front of them. Our next step, prior to in-home deployment, is to refine and improve algorithms used to predict user actions, particularly improving the use of the fiducial markers. This could be done by observing the dressing actions without guidance to characterize dressing patterns for a variety of users. With an improved understanding of how to use the fiducial markers' information to detect dressing status, we can then find alternative options of adding other less visible identifiers to clothing and then extend the capability of the system to detect additional articles of clothing. We then plan to test a subsequent version of DRESS with experienced caregivers of PWD as they engage in unstructured dressing so that we have a more complete understanding of the system's abilities in a context that is closer to the one that it aims to address.

Limitations

There are several limitations to this study primarily because it is an initial proof of concept study. Foremost is a lack of system testing by PWD. One of our IRB's refused to allow the involvement of caregivers or PWD in testing of the DRESS system until we submitted data that documented operational performance and validity of clothing identification. This study has provided that key data and we plan to test a subsequent version of DRESS with experienced caregivers as noted above. Although the focus groups provided significant family caregiver input, we did not include their care recipients. Three of the four PWD who accompanied their caregivers out of necessity, gave no input due to attention, comprehension, and/ or difficulty with speaking. One late early stage PWD was able to articulate that he would "need to see if he could use it". As we anticipated, given the disease stage of these target end-users, it was beyond their cognitive capacity at this initial stage to conceptualize DRESS operations. We will pursue their input when we can offer a more concrete version. Additionally, testing of the operations was limited to a controlled laboratory environment, and deployment into the real world of homecare settings with PWD is necessary to gain the practical understanding of implementation issues. Finally, when the technology is matured it will be necessary to test for intervention outcomes with a sample sized for adequate statistical power. Despite these limitations, this study was able to obtain critical qualitative and quantitative foundational data to support project advancement and enable future inclusion of PWD.

Conclusion

DRESS is being developed to offer an innovative cognitive orthotic designed to uniquely tailor to PWDs' responses while accommodating their daily fluctuations in cognition. Caregivers with dressing difficulty experiences strongly affirmed the need for more dementia relevant dressing interventions and the potential for DRESS to be the system of choice. They enthusiastically embraced the concept of using context aware affective technology as a unique and desirable means to respond to the daily fluctuations in family members' cognition. The caregivers' input improved the system's original design to make it more relevant and practical in its application. The resulting DRESS conceptual prototype system was able to be successfully built and tested to demonstrate successful technical operations and valid clothing identification. Future research is needed to integrate the findings from this stage into the alpha stage for implementation readiness and field testing with PWD.

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