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A Survey of Tablet Applications for Promoting Successful Aging in Older Adults

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ABSTRACT Aging well consists of the following components: management of chronic conditions, maintenance of physical health and cognitive health, and active social engagement. However, the increasing life expectancy, rising healthcare costs, increasing number of older adults, and decreasing number of care providers pose challenges to the maintenance of different components for aging well. To that end, technological innovation can help to augment human need and capability along the different components, and help overcome the potential barriers in aging well. In this paper, we summarize the published studies for different tablet-based applications designed specifically for older adults targeting different components of aging well. We discuss the strengths and weaknesses of the applications for each component, and identify the opportunities to develop a cohesive application for addressing the different components of aging well.

INDEX TERMS Older, adults, technology, tablet, successful, integrated.

I. INTRODUCTION

"Successful Aging" or aging well, as defined by Rowe and Kahn, encompasses the following aspects: absence of disease, maintenance of physical and cognitive health, and active social engagement [1]. However, studies have shown that the majority of older adults (persons aged 65 years and above) do not meet this criterion of "Successful Aging" [2] for a number of reasons. Firstly, this definition fails to acknowledge older adults with chronic conditions and functional disabilities, who self-report aging successfully [3]. Secondly, chronic conditions are inevitable with age [4]. Therefore, a true definition of "Successful Aging" needs to include management of chronic conditions, along with the maintenance of physical, mental health and socio-emotional health (Figure 1).

Advances in public health interventions and medicine have led to a significant increase in life expectancies and the number of older adults worldwide. In United States, the number of people 65 years and above will approximately double from 38.9 million in 2008 to 72.1 million by 2030 [5]. In Europe, the number of people 65 years or older will rise from being 17.1% of the total population to 30.0% by 2030, and even higher in countries such as Japan and Spain where life expectancies are abnormally high [5]. Some challenges associated with this projected increase are:

FIGURE 1. Successful aging: different components.

- **Increasing healthcare costs**: The healthcare cost associated with the treatment of an older adult is three to five times higher than that of an average age adult [6], with a projected 25 percent increase by 2030 [7].
- **Increasing dependency ratio**: This ratio describes the number of individuals between 15 to 64 years [8] who

are available to care for people aged 65 years and older.

- **Decreasing number of direct healthcare workers (nurses, home-health workers)**: This has been linked to high-stress, low salary, and poor work benefits [9] of the existing workforce.
- **Increasing number of informal care-givers (family members providing care)**. This is the direct consequence of the above two factors and has been associated with high stress and health decline of informal care-givers. In addition, the caregiving family members sacrifice wages. In fact, the **employers** in the United States are estimated to **lose** about 33 million dollars due to absenteeism of these care providers [10].

In this era of technological innovation, the potential of technology is being explored to overcome these challenges. More specifically, it is being used to bridge the gap between older adults and the care providers, and to empower the older adult to take charge of their own health. This advancement is marked with a gradual increase in the number of older adults adopting tablet technology [11]. Tablet appeals to them due to its portability, and absence of external hardware such as a mouse and a keyboard [12], [13]. In fact, using technology to solve their everyday challenges is helping older adults realize that they can use tablets to stay independently in their own homes as long as they can. As a result, applications addressing more specific aspects of "Successful Aging" are being developed and studied [14]. Examples include medication management applications that empower the older adults to manage their medication intake for improved physical health; and online social networking sites and forums that help older adults stay socially engaged and connected for better socio-emotional health.

II. CONTRIBUTIONS

Most review articles discuss advantages and disadvantages of smartphone/tablet based solutions belonging to a specific domain of "Successful Aging". Dayer et al. [15] reviewed medication adherence applications available on different smartphone platforms. Joe and Demiris [16] studied the impact of mobile phone on health of older adults. A recent review by Higgins highlighted the usefulness of smartphones in achieving health and fitness goals [17]. Other reviews study older adults' touchscreen interactions [16], [18]. In this survey paper, we describe tablet-based studies involving older adults since the introduction of the iPad in 2010, addressing different components of "Successful Aging". We also discuss challenges and opportunities in each domain, and conclude with a suggestion for integrating all domains into a single platform.

This paper is organized as follows: Section III describes the usability studies for tablets conducted with older adults and studies comparing older adult touchscreen performance with laptop/desktop performance. Sections IV - VII include tablet-based studies within each domain of "Successful Aging". Finally, we conclude by highlighting further research directions and rationalizing the need for and challenges around implementing a tablet-based integrated platform for "Successful Aging".

III. TABLET ADOPTION

With the inception of the iPad (tablet) in 2010 and increasing popularity of tablets among older adults [11], it is gradually becoming important to identify the advantages and challenges faced by older adults in tablet adoption. Few studies have been conducted to evaluate the usability of tablets for older adults. One of the initial studies was conducted by Werner et al. in 2012 for evaluating the general usability and acceptance of a tablet among older novice users [12], [19]. Eleven novice computer users (60 years and above) were recruited to perform a set of predefined tasks that included turning on the tablet, searching with Google, reading and composing an email, and finally searching a video on YouTube. In general, the study participants found the tablet easy to use, and were satisfied with complexity of the study tasks. Due to inexperience, everyone needed some time to get familiar with the nuances of the device, but the learning experience was easier and faster than their expectations. The magnifying feature was important attribute for readability of the device.

In another study, 77 participants (aged between 73–87 years) provided qualitative feedback on tablet (iPad) usability [13]. The participants used the tablet for at least five minutes and rated using a 10-point rating scale, 22 recommended tablet-based applications. This study found similar findings as [12], [19]. In addition, the tablet promoted social engagement, and increased interpersonal and intergenerational communications. The study also found that the absence of keys and mouse made the technology (tablet) easy to use. The participants appreciated the mobility using the tablet but found the tablet to be heavy and faced difficulties with the screen resolution. In another study, researchers found that older adults preferred to use applications related to lifestyle, technology, digital content, independence and for gathering information for younger family members [20]. These categories were derived from data based on observations and interviews conducted in 2012-2013 with nine participants having less than 2 years of tablet experience. The participants in this study found the downloading applications to be easy, and the operating system to be interactive and customizable.

In addition to these usability evaluation studies, studies have been conducted to compare older adults' touchscreen performance against desktop/mouse performance. For example, Findlater et al. compared the performance of 20 older adults and 20 younger adults on four desktop and touchscreen tasks: pointing, dragging, crossing and steering [21]. They found that even though the performance of older adults was slower than that of the younger adults on both the devices, the performance gap was smaller for the touchscreen than that for the desktop. The older adults found steering task with desktop and dragging with touchscreen as the most difficult task. A decrease in error rate for older adults was reported using the touchscreen over that with a desktop. Further, there was no significant difference in error rates using the touchscreen among younger and older adults. There was also no significant difference in subjective difficulty (measured using a rating given by the participant for each task) among tasks using touchscreen in older adults, and also between older and younger adults.

Kobayashi et al. compared the touchscreen performance between a tablet (large touchscreen device) and a smartphone (small touchscreen device) among nineteen participants in a week-long study [22]. They found that, on both devices, dragging and pinching (zoom in and out) was easier than tapping (click on a target for a small period of time), even though the former action required greater hand movement. This is in contrast with the findings for older adults with motor disabilities [23]. The performance on all the tasks improved after a week of practice for both the devices. For all tasks, the completion time was significantly lower on a tablet versus on a smartphone, primarily because of the larger screen size.

Despite these positive findings, tablets may pose several challenges to the older adults. Israel [20] have highlighted some barriers associated with using tablets, including complexity of the technology, software complications and fear of harming the screen/tablet. Favilla et al. reported some difficulties faced by older adults in using tablet touchscreens [24]. Firstly, the capacitive screens do not provide any haptic response [25]. Secondly, finger swiping, one of the most common movements for capacitive screens, is normally difficult for older adults [26]. Further, older adults, especially those with dementia and reduced motoring abilities, may find it difficult to exert and maintain sustained pressure on a touchscreen [27]. They may also find the tablet heavy and screen resolution unoptimal (glare) [13]. To manage the weight, older adults either use some form of support (table/pillow) or avoid hand-holding the tablet [13], [26]. Finally, older adults find difficult to type using the onscreen keyboard [12].

A. LIMITATIONS AND OPPORTUNITIES

All the studies evaluating tablet usability among older adults [12], [13], [19], [20] were conducted around the same time (2012-2013), with the same tablet technology (iPad) and similar age groups. However, the studies were conducted in different settings (laboratory, home, home-care and work) and with different sample sizes. Qualitative usability measures (observations, focus groups and interviews) were used for evaluating the usability of these tablets. Future research can benefit from objective usability metrics: task completion time, number of errors committed, and number of successful tasks. Research has been conducted to evaluate specific tasks (dragging, pointing, pinching) on a touchscreen using these quantitative measures [21], [22]. However, these studies were conducted with applications designed specifically for performing study tasks.

The existing studies were conducted with earlier versions of iPads [12], [13], [19], [20]. The tablets have drastically evolved since the time these studies were conducted. These imply that the disadvantages regarding tablet adoption (heavy weight and screen resolution) could probably be already outdated. Tablets have become lighter and slimmer, suggesting the weight issue identified in [13] may have been already resolved. Tablets have become cheaper due to advances in technology and increase in tablet popularity [11]. The price of a tablet has been reported to be a challenge in tablet adoption among older adults [13], [20]. Further, the memory/storage of a tablet can now be extended with external storage cards (SD cards) countering the storage limitation. However, we might need to address new challenges due to differences in tablet specifications [weight, resolution, size], including impact on touch sensitivity, font size and various other aspects of usability. Stronger and effective conclusions about the usability of new releases of tablets could be reached by using larger sample, by evaluating performance using quantitative metrics available for usability evaluation and by comparing tablets with different specifications [operating systems (Apple, Android and Windows)].

The results should be further analyzed with respect to demographic variables (age, gender, years of education) and experience using tablet/technology because computer knowledge, computer anxiety, and learning ability are found to be influenced by these factors [28]. Moreover, longitudinal tablet studies could be conducted for capturing any fatigue arising from prolonged usage and for studying the effect of chronic conditions that affect mobility, visual senses, and bones (finger movements). The tasks used for evaluation were predefined for the studies. In longitudinal studies, we can install an application for capturing application usage (application name, and duration of usage for the application) to identify application usage frequency and popular categories among older adults. Though one of the present studies [20] identified the popular application categories, it was only based on the qualitative data (interviews and observations). A combination of qualitative and quantitative analysis can help us better understand tablet use among older adults.

IV. CHRONIC CONDITION MANAGEMENT

The management of chronic conditions involves a number of tasks including adhering to a medication regimen and managing disease symptoms. In this section, we focus on describing medication management applications because the majority of older adults take a large number of prescribed medications [29], arising from multiple chronic conditions [30]. The multiple chronic conditions and the high number of prescribed medications often result in a complex medical regimen, which often leads to medication non-adherence [31]–[33]. Medication non-adherence can affect physical health of the older adults because it precludes the intended therapeutic benefits of the prescribed medications and often results in co-morbid chronic conditions. Further, it also increases healthcare costs [34] and the rates of hospital readmission [35].

There exist many direct and indirect measures of medication adherence [36]. Some of the direct methods include measurement of biological markers in blood and direct observation therapy. While these direct methods provide accurate estimation of medication adherence, they are quite expensive and could be invasive. The indirect methods include electronic medication dispensers and pill counting. These methods are fairly inexpensive and can act as a good proxy for estimating medication adherence. However, these have a dependency on the reliability of the users because there is neither tracking of the actual intake of the medication nor any involvement of direct physiological measurement.

Prior to the introduction of iPad in 2010 and the subsequent popularity of tablets, mobile phone applications were developed for medication management. The majority of these applications were standalone with no integration with the care providers. Text-based mobile-based medication reminders have been proven to be effective in improving medication adherence [37]. One of the earliest smartphone application for medication management developed for older adults is UbiMeds [38]. Its design was based on the literature review of the issues associated with medication non-adherence. This iPhone-based application provides automated reminder with an image of the medication, directions, dosage and a button for confirming intake. If a medication is missed, it informs the physician. The application is linked to the user's personal health record (PHR) where prescription/medication information can be directly updated by the clinician. Further, it provides information on side effects and additional dosage instructions for the prescribed medications. The application was not evaluated for usability and effectiveness in improving medication adherence.

A few tablet-based medication management applications have been specifically developed for older adults [39]–[41]. The majority of these applications have been developed using an iterative, user-centered design approach with the older adults as the target users. For example, prior to the development of Mediframe [39], a quantitative study with 360 older adults and a qualitative study with nine older adults were conducted for identifying the issues with medication adherence [42]. These studies have found that forgetting to take medication, lacking knowledge about a medication and not getting support from a care provider are some of the important challenges in adhering to medication regimens. The primary feature for these applications is to provide reminders when a medication is due. Some of these applications allow users to customize these reminders [39]. Usually, these reminders provide a list of the medications due at a particular time, along with the dosage information, image of the medication and warnings (if any). The user is required to confirm the intake of a medication.

Only one application (ALICE) has been evaluated for its effectiveness in improving medication adherence [40]. A randomized control trial was conducted for 3 months with 102 older adults, equally divided into experimental and control groups. The participants having multiple chronic conditions and taking multiple medications, and capable of managing their medications by themselves, were included in the study. The participants filled out a custom questionnaire for evaluating the rate of missed does and medication errors, 4-item Morisky Medication Adherence Scale (MMAS-4) [43], and perceived health status at the beginning and at the end of the study. The participants in the experiment group received the ALICE application installed either in a Wi-Fi enabled Android or iPad tablet. The participants in the control group, on the other hand, only received information on the risks associated with their medications and the common medication errors.

Even though the majority of the participants required assistance in navigating ALICE despite initial training, they felt that using ALICE has improved their medication intake habit. The study found an increase in treatment adherence (as measured by MMAS-4) and a decrease in number of missed doses among the participants in the experiment group at the end of the study. However, there was no statistically significant difference in the reduction of medication errors from the beginning of the study, when compared to that at the end of the study for both experimental and control groups. Further, a statistically significant difference in cholesterol levels were observed, even though there was no change in the levels of glycated hemoglobin, blood pressure and perceived health status for all the participants at the end of the study. A positive and significant correlation (Pearson's) measuring patient compliance was observed between MMAS-4 and the medication reminders generated by ALICE.

A few applications, specifically for older adults have been developed for minimizing medication errors and improving knowledge about medications. Studies have shown that if a person has knowledge about his/her medications, he/she would take medications as directed, thereby adhering to his/her medical regimen [36]. One such application for minimizing medication errors is Colorado Care Tablet (CCT) [44], [45]. CCT, a tablet-based application for medication management during care transitions, was developed using an iterative, participatory design approach for minimizing medication errors. A user can enter medications by scanning the barcode for the medication, manually using the code or selecting recently picked ones from the pharmacy. The user can easily access information related to a medication (retrieved from National Library of Medicine's MedlinePlus). The application can generate memo (containing the list of current medications and related potential questions that the user may ask) for promoting effective communication with the physician. Further, it can generate notifications for critical care assistance.

Tumedicina (YourMedicine), a smartphone-based and tablet-based application, allows older adults to scan the EAN-13 (barcodes) and QR codes on the medication packaging [46]. Upon scanning, the application displays the name, dosage, instructions for use, warnings if any, expiration date and the next visit to the physician. This information is also available in audio format. A study with 61 older adults (average

age of 68 years) was conducted for user evaluation of this application. The participants found Tumedicina easier to use and verbal messages simple and clear. There was no difference in satisfaction between participants with no or previous technology experience. The application was best valued by participants who had used pillbox or packaging notes for managing their medications.

A. LIMITATIONS AND OPPORTUNITIES

The majority of these applications provide no connectivity with the care providers/clinicians [39], [41]. This communication is very important to gather reasons for non-adherence. Moreover, this communication is becoming particularly crucial with the increase in older adults [5] and continual decrease in the number of care providers [8], [9]. Only ALICE reports the number of missed doses and medications taken to the clinician and the care provider, listed by the user using 3G service at the end of the day [40]. However, it does not provide any reason for the missed doses or medications. Moreover, these applications do not provide alternate functionality for providing responses to a medication reminder, in case this reminder is overridden [47]. The majority of these applications require the medication list to be entered by the older adults themselves [39], [40]. However, the participants in the study for evaluating ALICE had their prescription information preloaded in the application at the beginning of the study. S4S Medical Assistant [41] created a third party service for allowing care providers to enter this list. This medication entry is a complex and cumbersome process, given the complex medical regimen for older adults. This process could demotivate the older adults from using the application. These medication management applications do not provide offline usage functionality, which could become an important limitation when deploying these applications in a low socioeconomic group.

The majority of the studies evaluate the usability of the applications [38], [39], [44], [46]. However, there is only one study that evaluated the effectiveness of the application in improving medication adherence using experimental and control groups [40]. The study demonstrated a potential for using tablet-based applications for medication management. There was an improvement in treatment adherence and reduction in medication errors at the conclusion of the study. However, the study only measured unintentional medication errors. As there is no gold standard for measuring adherence [48], a combination of different methods should be used for measuring this adherence. Moreover, people, sometimes, do not take the prescribed medications purposefully, even when they do remember to take the medication. The power of technology (scanning barcodes or QR codes) or even submitting pictures of the intake could be employed as secondary measures for measuring adherence. In addition, physiological measures could be used for evaluating the effectiveness of these applications in improving/maintaining medication adherence. Few such measures including cholesterol and blood pressure were used in the evaluation of ALICE. However, these measures cannot be generalized because they depend on an individual's chronic conditions.

V. PHYSICAL HEALTH

Maintaining physical health involves doing physical activities and eating healthy. In fact, about two-thirds of the factors for aging well depends on one's lifestyle [49]. In older adults, regular and moderate intensity of physical activity has been shown to reduce the risks of the onset of chronic conditions like cardiovascular disease [50], type II diabetes [51], osteoporosis [52], hypertension [53], depression [54], and rheumatoid arthritis [55]; weight maintenance/obesity [56]; and improved cognitive function [57]. It also positively impacts quality of life [58], promotes independent living among older adults [50] and reduces risk of mortality [59]. In spite of benefits from physical activity, sedentary lifestyle (lack of physical activity) is quite prevalent among older adults in United States. In fact, according to the 2014 Behavioral Risk Factor Surveillance System (BRFSS), only 14.4 percent of older adults, aged between 65-74 years, and only 7.9 percent of adults, aged 75 years or more, met the recommended levels of physical activity (both aerobic and muscle-strengthening activities) [60]. Thus, to promote physical activity among older adults (under Healthy People 2010 initiative) [61]; low-cost, effective and sustainable interventions have been developed. These interventions (computer-tailored) have been proven to positively change physical activity among older adults.

A number of tablet-based applications have been designed to promote physical exercise among older adults [62]–[65]. For instance, Silveira et al. developed a tablet-based application, ActiveLifestyle to aid strength exercise among older adults [62], [66]. It assists and monitors the older adults during autonomous home-based physical workouts. Step-by-step instructions and a video demonstrating an exercise help the user perform the exercise. Upon completion of the exercise, the user provides feedback on his/her performance. The user's progress towards the goals set by the user is shown through a metaphor of a flower. The flower grows at the end of every workout session. Further, the flower has a mood status, reflecting the daily mood of the user, entered at the end of the entire workout session. The application provides group and individualized motivational messages to the user for helping him/her achieve the workout goals.

Thirteen older adults (70 years and older), with no severe illnesses were trained to use the *ActiveLifestyle* application for two weeks, for performing balance and strength exercises. 11 out of 13 enrolled participants completed the study. The majority of the participants intended to use the application again and would recommend it to their friends/family. The participants also appreciated the training videos. However, they did not like the sound of the alarm. The participants appreciated the flower metaphor and felt it motivating. The social group motivated the participants as well. However, the mood status of the flower did not have a high impact on their motivation.

Further evaluation of *ActiveLifestyle* has been performed with 44 older adults [62]. This was the first study assessing the effectiveness of a tablet-based health intervention for older adults. Three treatment groups were compared: (a.) an individual group receiving the individual version (only individual motivational strategies); (b.) a social group using the social version (both individual and group motivational strategies); and (c.) a control group that performed exercises using printed instructions with no motivational strategies. 33 older adults completed the study, with the highest attrition rate in the control group. The study found statistically significant differences in adherence to the training plans (ratio of completed workout sessions by each participant divided by the total number of possible training sessions) between the social and control groups, and between individual and control groups. However, there was no significant difference in this adherence between the social and the individual groups. There was an overall increase in gait speed for all the participants at the conclusion of the study, though there was no significant difference between the three groups. The self-motivational strategies worked best for the individual group while the social motivation suited the social group, although the majority of the participants in the individual group felt that it would be more motivated to use the social version. There was only a significant change in the behavior score among the social group. Thus, based on the results of the study, it can be concluded that a combination of physical exercise and IT enabled motivational strategies can be effective.

In another tablet-based application, Embodied Conversational Agent (ECA) was used to motivate older adults to walk [63]. ECA is an animated character that simulates face-to-face conversations using voice, hand gesture, gaze cues, and other nonverbal behavior. A study with 263 older adults was conducted to test the effectiveness of this application. The intervention group received a tablet computer with the ECA application installed for first two months of the study, a pedometer for recording the walking steps, and a data cable for connecting the pedometer with the tablet. The control group only received a pedometer. Interviews were conducted at the end of 2 months and 12 months of the study. The average steps recorded by the intervention group were greater than that by the control group for both evaluation time points, even though there was a decrease in average steps recorded from 2 months to 12 months. However, the decrease in average count (in both groups) specifically occurred among participants with inadequate health literacy. An increase was observed for participants with high literacy. The participants in the intervention group were satisfied with ECA.

An eight week study by Korean researchers has demonstrated the effectiveness of an iPad based exercise program in improving cognitive status, and exercise self-efficacy among the intervention group [64]. Sixteen participants in the intervention participated weekly in a 30-minute group exercise training class in a senior living. They performed one exercise at least 3 times a week watching training videos on an iPad. Ten participants in the control group were part of a once-a-week group-based yoga program at the senior center.

Crandall et al. developed a tablet-based application called Bingocize, a combination of Bingo and exercise, developed to promote exercise and health education simultaneously. A number selected in this application corresponded to a health question or an exercise to be performed by the participants [65]. A study with 8 participants in the experimental group and 7 participants in the control group was conducted for 10 weeks to test the effectiveness of the application. The study found a significant difference in functional performance and gait velocity between the two groups. However, no difference was observed in arm curl movement. However, the study proved the effectiveness of a multi-modal application (combining health education and exercise) but the findings cannot be generalized due to the small sample size.

A. LIMITATIONS AND OPPORTUNITIES

The majority of the studies were short term studies and employing small sample sizes. Though studies with a small sample size are important for feasibility analysis, it can be challenging to draw statistically significant conclusions about the effectiveness of the applications. These studies also do not take into account the effect of gender, age, mood, weather and chronic conditions in the analysis. Furthermore, the majority of these studies have a selection bias: non-random selection of participants having technology experience, no severe chronic conditions and no cognitive impairment. These studies do not take into account the effect of the applications installed in the tablet that can provide further motivation and improve social engagement. Virtual Social Gym [67], a tablet-based application currently under development, has a web-based Coach App that allows the older adults to connect virtually with the trainers, aided by Kinect and sensor devices.

VI. COGNITIVE HEALTH

A number of cognitive abilities such as memory [68], attention [69], executive functions [68] and processing speed [70] show signs of decline with age. Even though the majority of older adults experience mild cognitive decline, every older adult needs a good cognitive health to live independently. The decreased ability to perform certain tasks or lack of mental stimulation can become a source of constant stress and consternation. It can also progress into serious conditions whereby an individual's ability to engage in various health maintenance behaviors such as medication adherence [71] or activities of daily living [72] is severely impacted. Finally, cognitive limitations can increase older adults' dependence on caregivers that can become expensive over time [73].

Fortunately, our understanding of age-related changes in basic cognitive functions, interrelationships among them and their ability to predict higher order cognitive functions is quite advanced. The field of cognitive neuroscience claims that appropriate cognitive training and therapeutic techniques can not only slow cognitive decline but they also may reverse/improve cognitive functions of affected older adults [74]. Therefore, for the past three decades, researchers have explored two main approaches for improving and maintaining cognitive and neural functions in older adults. The first approach seeks to target specific cognitive functions through computer-based cognitive training exercises. The second approach is concerned with influencing social, intellectual, and emotional engagement to improve neural and cognitive functions.

Over the past decades, video games have been extensively studied for their impact on cognitive health of older adults. Researchers have been able to establish that playing video games has numerous cognitive advantages for older adults. Video games have been shown to produce domain-specific improvements in cognitive abilities of older adults [75]. The improvement effects have been shown to transfer to other untargeted cognitive domains that have similar or different processing requirements [76]. The acceptance factor of video games is also high due to their interactive nature. However, video game research has faced its share of limitations. One major limitation of the video game studies is that they have not shown improvement in episodic memory – a cognitive function that has the most profound influence on an individual's health behaviors.

Recently, interest in using tablets to improve cognitive health of older adults has been growing. Researchers have found that learning tablet skills and maintaining sustained tablet engagement involve some of the most desirable cognitive functions in older adults i.e. episodic memory, executive function, long-term memory, working memory and reasoning. Chan et al. studied the effects of learning tablet skills in older adults by comparing three conditions [77]. The intervention group consisted of eighteen older adults who received extensive training in using a tablet and associated applications for 15 hours per week for three months. The remaining participants were divided into two control groups. The first control group (Placebo) engaged in passive tasks requiring little new learning, whereas the second control group (Social) had regular social interactions and no new learning. Researchers found that, compared to both control groups, the intervention group experienced a greater improvement in episodic memory and processing speed.

The interaction modality and real-estate limitations of tablet computers require researchers to pay attention to the usability aspects of the interfaces. Therefore, Lopez-Samaniego et al.'s study specifically assessed the usability of their system as opposed to measuring its impact on the targeted domains of memory and processing speed [78]. Their game consisted of memory and mathematical problem-solving tasks that could be played using the tablet touchscreen or a LEGO robot. Nine older adults (65 years and older) with moderate physical limitations and cognitive impairment provided qualitative feedback on their experience with both the modalities. Even though participants were satisfied with the game and found it enjoyable, they faced some difficulties in using the touchscreen and game's interface. In particular, applying pressure on the screen and targeting the exact touch spots (such as alphabets on keyboard) were challenging. On the game's interface, participants desired to see graphical as opposed to textual instructions, and a higher color contrast. The issue of background screen color was also explored by Yamazaki and Eto [79]. In particular, they explored the effect of screen's background colors on older adults' ability to pay attention while performing an attention seeking task. The study participants were asked to count circles on different background colors of a tablet screen. The results indicated that performance was best when black circles were displayed on a blue screen.

Tablet-based training programs have also been developed for cognitive rehabilitation of older dementia patients. A noteworthy example is Padua Rehabilitation Tool (PRT). This application was evaluated for both its effectiveness and usability in fifteen older adults with dementia by comparing three treatment conditions: traditional (paper-based), tablet-based, and no treatment [80]. Both traditional and tablet groups showed significant improvements in their cognitive functioning but some differences were observed. The tablet group showed improvement in other associated psychological conditions while the traditional group did not. The traditional group maintained the effects of the intervention one month after the intervention but tablet group did not. In terms of its usability, the tablet group was enthused by the application, and found it easy to use and engaging. Researchers believe that the main success of PRT was its graphical user interface that was designed in consultation with the target population. The interface provided visual and auditory feedback at the completion of every task. The difficulty levels of the tasks were adjusted according to user's abilities, keeping the users engaged in the training. This study also established the importance of personalization in interface and algorithm design for cognitive health in older adults. Studies with video games have shown that personalized and adaptive designs improve cognitive functioning of older adults [74], [81].

Research also suggests that domain-specific cognitive benefits can be obtained from social interactions in the context of cognitive training. This is specifically demonstrated in Myhre et al. study where a group older adults using Facebook was compared with a control group using an online diary [82]. The experimental group was trained to use Facebook and the control group was trained to use an online diary by Penzu.com in the first week of the study. During the following seven weeks, experimental group logged onto their Facebook page everyday and posted at least one status update (on their own pages) and one comment (on another participant's page). The purpose was to engage participants in back-and-forth dialogues among themselves. During this time, the control group was expected to login to their Penzu account everyday and write no more than three to five sentences to emulate the brevity of messages typically posted on Facebook. Results revealed significant improvement in processing speed and executive function associated with working memory in the

Facebook group. The researchers hypothesized that learning the complex interface of Facebook is responsible for directly improving the working memory in Facebook group and this improvement might have also transferred to another cognitive domain, i.e. memory update.

A. LIMITATIONS AND OPPORTUNITIES

Research shows that tablet-based applications can improve basic cognitive functions of older adults. However, the impact of these applications on complex behaviors such as prospective memory or goal attainment and their transfer effects to other domains of Successful Aging has not been studied. Important questions (such as, "is improvement in prospective memory associated with medication adherence?") still need to be explored. Moreover, user interface design requirements seem to change from one cognitive domain to the next. To develop truly effective cognitive health applications, interdisciplinary efforts are needed to integrate innovations from other fields (e.g. linguistics) as well as different areas of informatics (e.g. data science). This complicates the implementation of applications for promoting cognitive health. Another limitation is that the majority of these studies are concerned with measuring the impact of tablet applications using a rigid training regimen conducted in controlled settings. We did not find studies on effectiveness of casual games or autonomous training – two methods that might be more acceptable by older adults due to their simplistic nature. Finally, the results of the existing studies need to be confirmed with larger sample sizes and in longitudinal studies lasting over longer time periods.

VII. SOCIO-EMOTIONAL HEALTH

In old age, social connectedness and support play an important role in reducing loneliness and depression [83]. Yet, older adults are often socially isolated due to their physical limitations and/or life circumstances (e.g. death of a spouse, and preference for living independently). Fortunately, over the past decade, numerous information communication technologies (ICT) have been developed that can have a direct influence on individual's socio-emotional health. For example, emails and social networking websites like chatrooms, discussion groups and support groups facilitate social inclusion and relationship maintenance through back-and-forth messaging. The audiovisual tools can boost the experience of these online interactions by adding voice and video dimensions to them.

Studies show that ICT is effective in helping older adults develop and sustain new friendships, and experience a sense of community and belonging [84]. However, there has been some speculation around their impact on older adults' perception about their level of social support. Myhre et al. (we have described their study in Cognitive Health section) reported that participants in their study did not experience an improvement in their perception of social support [82]. The researchers had hypothesized that back-and-forth online dialogue on Facebook would increase social support variables in older adults but their study suggested to the contrary. It is possible that the study design which restricted participants' contact to study participants only (not the social media) is responsible for this outcome. Therefore, further research in understanding the impact of social media use on social support of older adults is needed.

Woodward et al. tried to address this question in their study using online communication tools but their results also suggest that ICT may not be effective in expanding older adults' social networks [85]. Essentially, the researchers collaborated with an older-adult-service-providing community agency to assess the effect of ICT use on socio-emotional health of older adults. Forty-five older adults used Internet-based applications such as Skype and email to connect with friends and family for six months. Thirty older adults who were not expected to do anything acted as control. Both groups were assessed for mental health and social support measures at the baseline, three months after the study, at the end of the study and three months post-study. The experimental group experienced an increased perception of support, particularly from their friends, and an improved quality of life compared to the control group. However, the experimental group did not report any statistically significant improvement in other measures of social support (i.e. number of people in the network and frequency of contact) or in loneliness and depression. This shows that ICT tools are effective in supporting existing relationships but not necessary in helping build new ones.

Meanwhile, other innovative applications have been evaluated for their ability to help older adults build new social connections. Engagement for Media Sharing (ENMESH) is a particularly important example in this area [86]. It is a tablet-based application consisting of a shared display where photographs and messages of all the connected users are visible in a cascading fashion. A user can move objects around and change their sizes using fingers, and other users can witness these interactions in real-time. Seven older adults (85 years and older) who did not know each other used Enmesh to share photographs and messages with each other for ten weeks. The analysis of shared content showed that producing digital content provided older adults with important opportunities for self-expression, creativity and social engagement. Sneak-peeking into their peers' lives and witnessing their peers' tablet interactions helped individuals connect with each other and find common interests. These promising findings behoove us to explore what other kinds of digital content production would appeal to older adults, and what type of media would be suitable for promoting different social relationship (such as inter-generational relationships, peer communication etc).

Apart from using tablet applications, older adults' interest in and desire to learn tablet skills can also reduce social isolation. Most studies report providing tablet training to participants in a group setting. Although older adults benefit most from personalized, one-on-one instruction, training with others provides an opportunity to connect and learn from peers. However, we did not find any research that specifically measured the impact of group training classes on social support measures for older adults. A study by Dasgupta et al. reports change and decrease in depression risk for 12 out of 16 participants [87]. The participants attended group-based tablet training classes for eleven weeks and used a tablet application for 31 weeks. Due to the limitations of their study methods, it is not possible to attribute decrease in depression to group-based tablet workshops. However, based on their empirical observations of increased participant contact both during and after workshops for the purposes of learning and teaching the tablet, the researchers suggest that participant's social support was greatly improved, explaining the decrease in depression risk.

Tablet learning has also been effective in improving social networks of older adults by enriching it with multi-generational dimension. Since the younger generation has grown up in the age of computers and technologies, they demonstrate greater comfort with these tools. As a result, teens can become effective mentors for older adults. A national volunteer-based program called Cyber-Seniors pairs older adults who want to learn to use computers and the Internet with teenagers who are willing to teach these skills. We did not find any study that reports social, emotional and physical benefits of inter-generational relationships, based on technology mentoring, on older adults. However, personal and social development benefits of these workshops on teens have been vastly documented.

A. LIMITATIONS AND OPPORTUNITIES

The major limitation of the existing studies is that they suffer from the lack of specificity when defining and measuring social support elements. This makes it harder for technologists to drive innovation and providers to prescribe technology for maintenance of socio-emotional health in older adults. Questions like ''how often email or Skype calls should be made with family or friends to reduce depression or loneliness?'' or ''how many people in the network are necessary for achieving feelings of support?'' and ''what kind of media sharing create feelings of connectedness?'' still need to be explored. A comparative evaluation of different ICT tools for their effectiveness in improving socio-emotional health of individuals and their privacy implications is needed. In general, we need to validate findings with larger sample sizes to ensure that we have the evidence base to drive policy changes and to encourage adoption of technology as a prescription for socio-emotional health of older adults.

VIII. DISCUSSIONS

In this paper, we have individually reviewed tablet applications for each component of ''Successful Aging'' and summarized their limitations (Table 1). In addition, we have also highlighted the successes and challenges of tablet adoption among older adults.

We found that older adults, in general, showed acceptance and satisfaction with the tablet technology and the studied applications, primarily because tablet applications were developed using an iterative user-centered design approach. Involving older adults in the design/development process bridges the gap between the target user (older adults) and the developer [88], resulting in products that are perceived, by the target population, as being intrinsically useful [28].

Studies' focus on user-centered design process shows that currently this field is in its nascent stage. Researchers are still understanding older adults' tablet interactions and validating design choices for different types of tablet applications. These goals can be accomplished via short-term user studies with small sample sizes. However, to evaluate true impact and effectiveness, long-term studies with larger sample sizes are needed that can bring greater understanding around technology use starting from its adoption to its abandonment. Usually, there is an initial learning curve, which might be steeper for older adults who may be slow in adopting technology. Moreover, individuals tend to stop using technologies after a certain period of time because they are either bored or have mastered the focus area of the application [89].

Studies that do measure effectiveness are usually concerned with evaluating individual components of ''Successful Aging'' in isolation. For example, the study conducted for evaluating the effectiveness of ALICE [40] only studied its effect on medication adherence as it is a tablet-based medication management application. Although it is important to rigorously study application's impact on the area of focus, secondary outcomes should also be considered. For instance, the effect of social engagement could be considered as a secondary outcome for ALICE as the tablet itself is shown to increase interpersonal communication and promote social networking [13]. Similarly, ActiveLifestyle [62], a tablet-based application for strength training, uses individual and group motivational strategies, and encourages group training that indirectly increase social engagement. However, the study does not evaluate this effect.

Moreover, we did not find any studies that consider the synergistic effect of the different components, which is ultimately needed for ''Successful Aging''. Since different domains of ''Successful Aging'' are interlinked, it is important to understand whether improvement in one domain leads to improvement in another. For instance, medication non-adherence (poor management of chronic conditions) increases the risk for co-morbid chronic conditions, thereby resulting in a deterioration of physical health. This poor physical health often limits the individual's ability to perform daily activities which, in turn, sometimes restricts social engagement. The restricted mobility or social isolation increases risk for depression, thereby affecting one's cognitive ability. In fact, combination of medication adherence and healthy lifestyle (physical exercise and cognitive stimulation) will help reduce the risk for certain chronic conditions like diabetes and hypertension. Thus, it is required to build applications that integrates different domains (physical, cognitive, social, medication adherence) in one platform to truly

TABLE 1. Successful aging components: intervention approaches and opportunities.

Component	Intervention Approaches	Limitations and Opportunities
Tablet Adoption	• Evaluating the usability of tablets using qualitative evaluation measures (focus groups and observations) • Comparing the performance of older adults using tablet and smartphone/desktop	• Short term studies • Lack of quantitative evaluation measures for studying the usability of tablets among older adults • Lack of diversification in tablets used • Privacy and ethical concerns
Chronic Condition Management	• User centered design • Medication reminders • Medication history	• Short term studies primarily evaluating the usability of the application • Limited number of studies evaluating the effectiveness of the application in maintaining medication adherence or health education • Restricted to no integration with the care providers/clinicians • Privacy and ethical concerns
Physical Health	• Video based training programs • Individual and group training programs • Motivational strategies • Multi-modal application (combining physical exercise and health education)	• Limited number of applications developed using an iterative, user centered design approach • Limited number of long term studies • Limited sample size
Cognitive Health	• Adaptive games • Personalized training • Domain-specific training • Transfer effects • User-centered design • Social cognitive gaming	• No exploration of casual and autonomous training • Limited interdisciplinary interactions • Small sample sized studies • Few long-term studies • Complexity of designing generalized training applications
Socio-emotional Health	• Social media • Social games • Internet-based communication • Native-tablet applications • Digital medium • Inter-generational learning	• Privacy concerns • Unspecific (socio-emotional) variable definition • Small sample sized studies • Limited variety of social applications • Comparison of different applications

achieve "Successful Aging" and to help the older adults stay independent as long as they can. However, it should be noted that in addition to being studied together, these individual applications should still be studied in isolation for evaluating the impact on the primary focus area.

IX. CONCLUSIONS

Research on the impact of tablet-based applications on different aspects of "Successful Aging" is in its nascent stage. However, the published studies, even though not free of limitations, provide evidence of positive impact on different components of "Successful Aging": management of chronic conditions (medication management applications), maintenance of physical and cognitive health, and social engagement. These different components of "Successful Aging" are interlinked. Hence, these components should be integrated or studied together for promoting "Successful Aging". An iterative, user-centered design approach would make this integrated framework acceptable among older adults. However, caution, especially with maintaining privacy and confidentiality, should be taken in designing and implementing this integrated framework.

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