Exploring Tangible User Interface for home-dwelling older people: Technology acceptance, social interaction and quality of life

Way Kiat Bong

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Abstract

Background: Quality of life is an important area of concern reflecting the health status and well-being of older people. It is a multidimensional concept, and older people often value social relationships as important elements in their quality of life. Previous studies have shown that information and communications technology (ICT) has the potential to enhance older people's social interactions. However, ICT designers often fail to consider the special needs of this user group. This has resulted in usability issues that contribute to low technology acceptance among them. Tangible user interface (TUI), which couples digital information with physical object, has been considered a more intuitive user interface for older people. Despite its potential, research in TUI for the older people's technology acceptance, social interactions, and quality of life has not been fully explored. There is therefore a need to design and develop TUI applications that accommodate the special needs of older people and study their impact on home-dwelling older people's technology acceptance, social interactions, and quality of life.

Aims: This research's overarching goal is to explore how TUI can impact on home-dwelling older people's technology acceptance and quality of life by enhancing their social interactions. The main aims of the study are threefold: to study the-state-of-the-art of TUI for the older people's social interactions and identify the knowledge gaps in this research field, to design and develop a TUI application based on the literature review and the older people's needs, and to study the impact of TUI use on the older people's technology acceptance, social interactions, and quality of life.

Methods: The research consists of three main stages: the systematic literature review; the design and development of the TUI application, Tangible Cup; and the three-month empirical study evaluating the use of Tangible Cup in relations to technology acceptance, social interactions, and quality of life. The systematic literature review followed the guidelines for systematic literature reviews in software engineering. User-centered design and co-design approaches then guided the design, implementation, and usability testing process for developing the TUI application used in the empirical study. Finally, a mixed of qualitative and quantitative approach was used in the three-month empirical study with 20 older participants where they used Tangible Cup to make calls and talk to each other.

Results:

Systematic literature review (Article I): The findings show that although TUI was introduced 20 years ago, very little research on TUI for the older people's social interactions has been carried out, i.e. 21 relevant papers were identified. Several recommendations were identified for future research, including involving older people in the whole research process from designing to evaluating the prototype, investigating the effect of TUI on older people's social interactions and health, conducting interdisciplinary research and longitudinal study in TUI for their social interactions, and developing guidelines for designing TUI for them.

Design and development of the TUI application (Article II): Tangible Cup was developed through four iterations of design, implementation and usability testing with 10 participants. Through the processes, a list of lessons learned was gathered which can serve as guidelines for what to consider when designing TUI for older people and when involving older people in the design process of TUI and general ICT.

Empirical study (Articles III and IV): The quantitative data shows that 12 out of 16 participants (20 were recruited, but four withdrew after one month) had positive changes in their technology acceptance. No statistically significant change in the quality of life was found. A few statistically significant correlations were observed between changes in the dimensions of quality of life and the dimensions of technology acceptance. The strongest correlation was a positive correlation between the general assessment of quality of life with attitude in technology acceptance. This indicates that using Tangible Cup could help the participants feel more positive when using ICT and thus assess their quality of life better. The qualitative data shows that some participants enjoyed the conversations. They even thought of further developing the friendship and meeting in person. Usability challenges, such as failure to log out properly and no battery level indication on the cup attachment, were identified. Nevertheless, all the participants agreed about the potential of Tangible Cup. Through the qualitative data analysis, we have also identified the target user group that TUI can be suitable for.

Conclusions: This interdisciplinary research contributes to adding new knowledge regarding TUI's potential for improving older people's technology acceptance, social interactions, and quality of life. When designing TUI for them, integrating TUI into their daily life and considering their diversity are important. The potential of TUI for the older people and research design considerations for implementing and evaluating TUI from the perspective of

technology acceptance, social interactions, and quality of life over a longer period time frame are among the new knowledge that clinicians, practitioners, and policy-makers can utilize.

Sammendrag

Bakgrunn: Livskvalitet er et viktig begrep som gjenspeiler eldre menneskers helsetilstand og velvære. Det er et flerdimensjonalt begrep, og eldre mennesker vedsetter ofte sosiale relasjoner som viktige elementer i sin livskvalitet. Tidligere studier har vist at informasjons- og kommunikasjonsteknologi (IKT) har potensialer til å øke eldre menneskers sosial samhandling. Men IKT designere synes sjelden å ta hensyn til de spesielle kravene til denne brukergruppen. Dette har ført til problemer med brukervennlighet som kan resultere i at denne gruppen har lav akseptering av teknologi. 'Tangible user interface' (TUI), som kobler digital informasjon med fysisk objekt, er ansett som et mer intuitivt brukergrensesnitt for eldre mennesker. Til tross for potensialet til TUI, blir det forsket lite på TUI med hensyn til eldre menneskers akseptering av teknologi, sosial samhandling og livskvalitet. Det er derfor nødvendig å utforme og utvikle TUI applikasjoner som tilpasses de spesielle behovene til eldre menneskenes og studerer innvirkninger TUI har på deres akseptering av teknologi, sosial samhandling og livskvalitet.

Mål: Denne studiens' overordnede mål er å utforske hvordan TUI kan påvirke hjemmeboende eldre menneskers akseptering av teknologi aksept og livskvalitet ved å forbedre deres sosial samhandling. Studien har følgende tre mål: Å studere rådende kunnskapsstatus pr i dag med hensyn til hvilken betydning TUI har for eldre menneskers sosial samhandling og identifisere kunnskapshull i dette forskningsfeltet, å utforme og utvikle en TUI applikasjon basert på litteraturgjennomgang og eldre menneskers behov, og å studere innvirkningen på eldre menneskers akseptering av teknologi, sosial samhandling og livskvalitet ved å bruke TUI.

Metodologier: Studien består av tre hovedstadier: en systematisk litteraturgjennomgang; en utforming og utvikling av TUI applikasjonen, Tangible Cup; og en tre-måneders empirisk studie for å evaluere bruken av Tangible Cup i med hensyn til akseptering av teknologi, sosial samhandling og livskvalitet. Retningslinjer for systematisk litteraturgjennomgangen i programvareutvikling ble brukt i våres systematisk litteraturgjennomgang. Deretter brukte vi brukersentrert utvikling og co-design tilnærming i prosessen med utforming, implementering, og brukbarhetstesting for å utvikle TUI applikasjonen som ble brukt i den empirisk studien. Til slutt brukte vi en kombinasjon av kvalitativ og kvantitativ tilnærming i den tre-måneders studien der 20 eldre deltakere brukte Tangible Cup for å ringe og snakke med hverandre.

Resultater:

Systematisk litteraturgjennomgang (Artikkel I): Selv om TUI ble introdusert for 20 år siden, er det veldig lite forsket på i TUI med hensyn til eldre menneskers sosiale samhandling, dvs 21 relevante artikler ble identifisert. Forslag for fremtidige forskning ble presentert, og anbefalinger inkluderer å involvere eldre mennesker gjennom hele forskningsprosess (fra utforming til evaluering av prototypen), å undersøke effekten av å bruke TUI applikasjoner med hensyn til eldre menneskers sosial samhandling og helse, å gjennomføre tverrfaglig forskning og longitudinale studie i TUI for de eldre menneskers sosial samhandling, og å utvikle retningslinjer for å utforme TUI for de eldre mennesker.

Utforming og utvikling av TUI applikasjonen (Artikkel II): Tangible Cup ble utviklet via fire iterasjoner av utforming, implementering og brukbarhetstesting med 10 deltakere. Gjennom disse prosessene ble nyttig lærdom som kan brukes som retningslinjer for hva bør vurderes når en utformer TUI for de eldre mennesker og når en involverer eldre mennesker i prosessen å utvikle TUI og IKT generelt, samlet.

Empiriske studie (Artikkel III og IV): Kvantitative data viser at 12 av 16 deltakere (20 ble rekruttert, 4 trakk seg etter en måned) skåret høyere med hensyn til akseptering av teknologi. Ingen statistisk signifikant endring i livskvalitet ble observert. Noen statistiske signifikante sammenhenger ble observert mellom endringer i enkelte dimensjoner til livskvalitet og enkelte dimensjoner i akseptering av teknologi. Den sterkeste sammenhengen var en positiv sammenheng mellom den generelle vurderingen av livskvalitet og holdningen til akseptering av teknologi. Dette indikerer bruk av Tangible Cup kan føre til at deltakerne opplever det mer positivt i å bruke IKT. De kan dermed vurdere sin livskvalitet bedre. Kvalitative data viser at noen deltakere satte positiv pris på samtalene. De kunne tenke seg å videreutvikle vennskapet og etablere personlige møter. Utfordringer når det gjelder brukervennlighet, er for eksempel at de ikke klarte å logge ut på en riktig måte og manglende mulighet til å identifisere indikasjon av nivå på batteriet på ‘cup attachment'. Alle deltakerne var likevel enige om Tangible Cup hadde positive potensiale. Gjennom den kvalitative dataanalyseringen har vi også identifisert målbrukergruppen som TUI kan være egnet for.

Konklusjoner: Den tverrfaglige studien bidrar til nye kunnskaper om TUIs’ potensialer i å forbedre de eldre menneskers akseptering av teknologi, sosial samhandling og livskvalitet. Når man utformer TUI for eldre mennesker, er det viktig å integrere TUI i deres daglige liv og ta hensyn til mangfoldet i den eldre befolkningsgruppen. Potensialet til TUI for eldre mennesker og betraktninger med hensyn til forskningsdesign ved implementere og evaluere

TUI i relasjon til akseptering av teknologi, sosial samhandling og livskvalitet over en lengre periode representerer ny kunnskapene som klinikere, utøvere, politikere og andre beslutningstakere kan benytte av.

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Articles

Article I: Bong, W. K., Chen, W., & Bergland, A. (2018). Tangible user interface for social interactions for the elderly: a review of literature. *Advances in Human-Computer Interaction*. DOI: **https://dx.doi.org/10.1155/2018/7249378**

Article II: Bong, W. K., & Chen, W. (2019). Tangible Cup for elderly social interaction: Design TUI for & with the elderly. *The Journal on Technology and Persons with Disabilities*, 64. DOI: **https://dx.doi.org/10211.3/210391**

Article III: Bong, W. K., Bergland, A., & Chen, W. (2019). Technology acceptance and quality of life among older people using a TUI application. *International Journal of Environmental Research and Public Health: Special Issue on Quality of Life: The Interplay between Human Behaviour, Technology, and the Environment*, 16(23). DOI: **https://dx.doi.org/10.3390/ijerph16234706**

Article IV: Bong, W. K., Chen, W., & Bergland, A. Exploring tangible user interface for social interaction and quality of life: The experiences of home-dwelling older adults. Under review, 2019.

Abbreviations

ICT	Information and communications technology
TUI	Tangible user interface
OPQOL	Older people's quality of life
TAM	Technology acceptance model
SMS	Short message service
WHO	World Health Organization
RFID	Radio-frequency identification
NSD	Norsk senter for forskningsdata (Norwegian Center for Research Data)

1 Introduction

The focus of this dissertation is on exploring and developing tangible user interface (TUI) to improve home-dwelling older people's technology acceptance, social interactions and quality of life. By providing a more engaging experience when using a TUI application for social interactions, it is hoped that they can have more positive attitudes toward accepting and using ICT and be encouraged to use ICT more often. When they become more socially active, they can have better social relationships and, hence, a higher quality of life. The term 'older people' refers to individuals aged 65 or older (WHO, 2002). This research aims to promote healthy aging, specifically targeting home-dwelling older people. In this dissertation, healthy aging implies that older people have a good quality of life as they age, which includes having good social relationships and participations.

The population is aging in many countries, and the hope is that they will age healthily. WHO (2019) defines health aging as "maintaining the functional ability that allows one to do the things you value, which means preserving both physical and mental capacity as one ages". Having a good quality of life is essential to healthy aging. In recent years, there has been growing interest in enhancing older people's quality of life (Bowling & Stenner, 2011)Older people's quality of life has been indicated as an independent predictor of several health outcomes (Bilotta et al., 2011; Kojima et al., 2016). Thus, it is important to ensure that older people have a good quality of life as they age.

Social relationships and participations have been considered essential elements in older people's quality of life and healthy aging (Bowling, 2009; Bowling, Banister, Sutton, Evans, & Windsor, 2002; Bowling & Stenner, 2011; Corner, Brittain, & Bond, 2006). Older people who have an active social life and good social interactions tend to have a higher quality of life (Antonucci, 2001; S. Cohen & Janicki-Deverts, 2009). However, for many reasons, older people face challenges in maintaining active social relationships and participations. One of the reasons is living alone (Christina Victor, Scambler, Bond, & Bowling, 2000). Statistically, older people are increasingly more likely to live alone (Reher & Requena, 2018). In the 28 countries of the European Union, 32.1% of older people live alone (Eurostat, 2017). In the United States (US), of the older people not living in nursing homes or hospitals, almost one-third, or 11.3 million, of them live alone (Aging, 2018).

Home-dwelling older people living alone may experience social isolation, which is associated with higher mortality rates, certain diseases, and a poor quality of life (Reher & Requena, 2018). Loneliness and social isolation among the aging population are significant concerns as they have varied negative impacts on older people's health (Cacioppo et al., 2002; Holmén & Furukawa, 2002; Nausheen, Gidron, Gregg, Tissarchondou, & Peveler, 2007; Patterson & Veenstra, 2010; Petitte et al., 2015; Laurie A Theeke & Jennifer Mallow, 2013; Tomaka, Thompson, & Palacios, 2006). A study exploring late-life loneliness in 11 European countries (i.e., Norway, Belgium, Germany, Poland, France, the Czech Republic, Russia, Lithuania, Romania, Bulgaria, and Georgia) found a high level of loneliness (i.e., 30–55%) among older men and women in Eastern Europe and a relatively lower (i.e., 10–20%) level in Western and Northen Europe (Hansen & Slagsvold, 2016). The findings also indicate a strong relationship exists between loneliness and lower socioeconomic status, poor health, and the absence of a partner.

With the help of Information and communications technology (ICT) tools, older people can enhance their social interactions and maintain an active social life (Barbosa Neves, Franz, Judges, Beermann, & Baecker, 2019; Chiu et al., 2016; Leonardi, Mennecozzi, Not, Pianesi, & Zancanaro, 2008). However, few ICT tools focus on the special needs of older people. A specially designed mobile instant messaging application (Bong & Chen, 2015), an assistive telepresence robot designed to facilitate the older people's social interactions (Koceski & Koceska, 2016), the ability of intelligent personal assistants, such as Google Assistant, Amazon Alexa, Apple Siri, and Microsoft Cortana to enhance older people's social lives (Reis, Paulino, Paredes, & Barroso, 2017), have been focused on in previous studies. However, these studies only included moderately skilled or advanced ICT users.

Older people are a diverse population (Bong & Chen, 2019; Hallewell Haslwanter, Fitzpatrick, & Miesenberger, 2018). They possess unique needs, behaviors, and attitudes in using and adapting to ICT (Neves & Amaro, 2012; Spreicer, 2011a; Teixeira et al., 2012). Most of them tend to be more skeptical of new technology, and they require more time and effort when learning and using ICT (Bong & Chen, 2015, 2019). Neves and Amaro (2012) studied older people's use and perception of ICT in Lisbon, Portugal, and found that a lack of functional ICT literacy was their main reason for not using a computer or the Internet. Many older people who have minimal computer skills suffer from 'e-exclusion' (Mancinelli, 2008). Conversely, the term 'e-inclusion' refers to developing "policies and social movements intended to encourage the use of digital technologies" (Morato, Ruiz-Robles, Sanchez-

Cuadrado, & Marzal, 2016) and using these technologies to enhance older people's social relationships (Leonardi et al., 2008) and quality of life (Olphert, Damodaran, & May, 2005). However, older people are vulnerable to e-exclusion because their needs are not addressed adequately, and thus, their skills have not kept pace with the transformation of ICT.

Hence, it is important to ensure older people's needs are addressed so that they are no longer vulnerable to e-exclusion. Previous studies have demonstrated the special needs of older people in learning and using ICT (Barnard, Bradley, Hodgson, & Lloyd, 2013; Bong & Chen, 2015, 2019; Vaportzis, Giatsi Clausen, & Gow, 2017). Most of the current ICT uses a graphical user interface (GUI), which allows users to interact with their electronic devices through graphical elements, icons, and symbols. Despite GUIs' advantages in making the interaction between users and electronic devices more intuitive and effortless (Hobart, 1995), older people still face challenges in using them (Al-Razgan, Al-Khalifa, & Al-Shahrani, 2014; Bong & Chen, 2015). Some older people have difficulty using touch screen gestures due to weak muscle control (Caprani, O'Connor, & Gurrin, 2012), while others find understanding icons and buttons to be a challenge (Bong & Chen, 2015). Therefore, a more intuitive user interface is needed.

TUI couples digital information with everyday physical objects and architectural surfaces, with the aim to enhance interactions between humans and digital information (Ishii & Ullmer, 1997; Ullmer & Ishii, 2000). A common TUI we use daily is a computer mouse, a physical object that we can control easily and interact with digital information on a screen. Spreicer (2011a) developed a TUI application called TanCu, which consists of a wooden base station, two cubes with large pictures and symbols on their sides, and a device with three buttons attached to the wooden base station. By placing the two cubes together with their dedicated side, users can choose to perform desired actions, such as sending an e-mail or a short message service (SMS) text message. The results of this study indicate that TUI can be a potential user interface for older people in learning and using ICT. However, despite its potential, few studies have focused on using TUI for older people's social interactions (Bong, Chen, & Bergland, 2018). Thus, the goal of this research is to explore the ways TUI can impact home-dwelling older people's technology acceptance and quality of life by enhancing their social interactions.

1.1 Structure of the dissertation

This dissertation consists of two main parts. Part I contains ten chapters, and Part II contains four articles that form the entire Ph.D. research. Part I is organized as follows. An introduction is given in Chapter One, and Chapter Two presents the background of the Ph.D. research. In Chapter Three, the aims and contributions are described and summarized to provide an overview of all the articles' research questions, main findings, and their relationship to achieving the Ph.D. research's overarching goal, as well as their contributions to the research field. The chapter is ended by summarizing the contributions of the PhD research itself. Chapter Four describes the systematic literature review, while Chapter Five describes the design and development process for the TUI intervention, Tangible Cup and Chapter Six presents the empirical study. The Ph.D. research is then discussed in Chapter Seven and concluded in Chapter Eight. The Ph.D. dissertation's references are listed in Chapter Nine, and the Appendixes are presented in Chapter Ten.

In Part II, the first article, the systematic literature review summarizes the state-of-the-art in TUI for older people's social interaction. This article identifies research gaps and provides recommendations for conducting research on TUI for older people's social interactions, including involving older people throughout the entire research process, focusing in the impact of TUI on older people's social interaction, and conducting interdisciplinary and longitudinal research on TUI for older people's social interaction. These recommendations were followed, and the identified research gaps were addressed accordingly in the second, third, and fourth articles. The second article demonstrates the design and development process of the TUI prototype for this research, Tangible Cup, and presents a list of lessons learned from the process. The third and fourth articles focus on a three-month empirical study of 20 older participants. The third article focuses on the impacts of using the Tangible Cup on their technology acceptance and quality of life and the association between these two outcome measures. The fourth article investigates older participants' experiences with using the Tangible Cup and its impact on their social interactions and quality of life. In this dissertation, the Tangible Cup is referred to as a TUI prototype during the design and development process, then a TUI application and a TUI intervention when applied during the empirical study and Ph.D. research.

2 Background

In this chapter, the key concepts used in this dissertation are explained in Section 2.1. The TUI concept is elaborated in Section 2.2, followed by describing older people's use of ICT, which is presented based on their attitudes and behavior, their technology acceptance, and the empowerment and user involvement of older people in using ICT. Older people's social isolation, loneliness, and living alone are then described in Section 2.4. Section 2.5 addresses older people's quality of life, which is a concept used in Articles III and IV. This chapter concludes by summarizing the research background and presenting the conceptual framework for this dissertation in Section 2.6.

2.1 Key concepts

The terms 'elderly' and 'older people' refer to people aged 65 or older (WHO, 2002). In this dissertation, the terms 'elderly,' 'older people,' and 'older adults' are used interchangeably. The Ph.D. research focuses on older people who are home-dwelling and live alone.

The term ICT was coined by Stevenson (1997). Referring to his definition, ICT includes the use of telecommunication technology, such as telephony, broadcast media, and all types of audio and video processing and transmission. These enable users to access, store, transmit, and manipulate digital information. According to the Information Technology Association of America (ITAA), information technology (IT) is the study, design, development, implementation, support, or management of computer-based information systems, particularly software applications and computer hardware (ITAA, 2008). It is then extended to include an increasingly important aspect of computing: communication. Therefore, by combining computing and communication, the term is ICT.

When they introduced the TUI concept, Ishii and Ullmer (1997, pp. 234-241) described it as allowing users to grasp and manipulate bits in the center of users' attention by coupling the bits with everyday physical objects and architectural surfaces. The term TUI can be defined as interface in which physical objects play a central role as both physical representations and controls for digital information (Ullmer & Ishii, 2000). Further details about the characteristics of TUI and how it has been adopted in prior research are presented in Section 2.2.

The World Health Organization (WHO) defines the term quality of life as "an individual's perceptions of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations standards, and concerns" (Group, 1993, p. 153). In Article III, quality of life refers specifically to the Older People's Quality of Life (OPQOL) questionnaire developed by Bowling (2009), which consists of eight dimensions: (i) life overall; (ii) health; (iii) social relationships and participation; (iv) independence, control over life, and freedom; (v) home and neighborhood; (vi) psychological and emotion well-being; (vii) financial circumstances; and (viii) leisure and activities. It is important to mention that in this dissertation, using the Tangible Cup did not appear to have an impact on any dimension of the OPQOL, including financial circumstances.

According to De Jaegher, Di Paolo, and Gallagher (2010), social interaction occurs when two or more autonomous agents co-regulate their coupling in such a way that their autonomy is not forfeited, and their relational dynamics acquire autonomy. Examples of social interaction include conversations, collaborative work, arguments, collective action, and dancing. Thus, any form of socialization involving at least two people is considered social interaction in this dissertation.

The final major concept addressed in this dissertation is technology acceptance, which has been studied since the 1980s (Davis, 1985; Davis, Bagozzi, & Warshaw, 1989). Davis (1985) proposed the technology acceptance model (TAM) as a valid theoretical explanation of what motivates people to use computer systems. This model is suitable for use in this dissertation's conceptual framework because it facilitates studying how TUI impacts older people's technology acceptance.

2.2 Tangible user interface (TUI)

The definition of TUI is presented in the previous section. In short, a TUI makes no distinction between 'input' and 'output.' It offers an intuitive design that allows tactile manipulation and physical expressiveness by coupling digital information with physical objects and environments (Cho, Kim, & Kim, 2013). According to Ullmer and Ishii (2000), TUI have three main characteristics:

1. Each physical representation (*rep-p*) is coupled computationally to underlying digital information (*model*).
2. Physical representations embody mechanisms for interactive control (*control*).

3. Physical representations are coupled perceptually to actively mediated digital representations (*rep-d*).

The main difference between the TUI and GUI models is the control in the TUI model is in a physical form, and there is no distinction between input and output (see Figures 1 and 2).

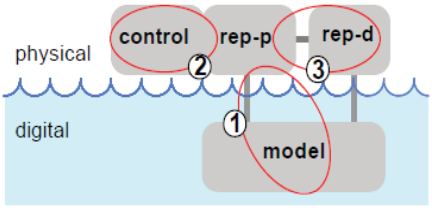

Figure 1. Ishii and Ullmer's (2000) TUI model.

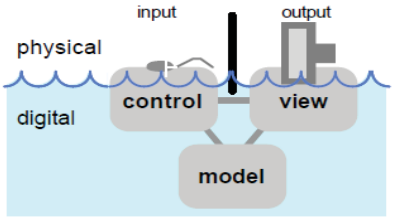

Figure 2. Goldberg (1984) GUI model.

Ullmer and Ishii (2000) suggested five kinds of tasks for which TUI is useful: (i) information storage, retrieval, and manipulation; (ii) information visualization; (iii) modeling and simulation; (iv) systems management, configuration, and control; and (v) education, entertainment, and programming systems. Ishii and Ullmer (1997) also identified three key features of TUI:

1. *Interactive surfaces.* Various types of surfaces, such as walls, ceilings, doors, and windows, are transformed into active surfaces that connect physical and digital worlds.
2. *The coupling of bits with graspable physical objects.* Digital information is incorporated into e graspable objects, such as cups, books, and cards.
3. *Ambient media for background awareness.* Ambient media, such as sound, light, airflow, and water movement, serve as background interfaces for digital worlds, where a human can perceive them.

Due to the advantage of coupling digital information on physical object, TUI has been adopted in many studies. For instance, social textiles were designed by Kan et al. (2015) as wearable computing textiles that enable social messaging and peripheral social awareness on

digitally linked shirts. Users' personal data, in the form of digital information displayed on the social textiles, can be controlled depending on their usage. Thus, they are suitable for use in a wide range of situations, including ice-breaking sessions, which do not require personal data to be shared, to connecting random people who have the same interests, which does require personal data to be shared. Cuendet, Dehler-Zufferey, Ortoleva, and Dillenbourg (2015) developed a TUI system called TapaCarp. The aim was to help train carpenter apprentices by using TapaCarp in classroom learning activities. The results show that the responses of both teachers and students were positive, and they were highly engaged in the activity.

However, despite its potential, research carried out in TUI for older people's social interactions is scant (Bong et al., 2018). Only 21 papers were identified when we conducted the systematic literature review in 2017 to study the state-of-the-art. Since then, several works have been published on TUI for the older people's social interactions. Spreicer (2019) developed *kommTUi*, a TUI application that aims to establish, maintain, and exchange communication for older people. By placing a token into a slot in *kommTUi*, older people can interact with the system, which can start a corresponding program on a computer (e.g., Skype or an email client). Fox (2018) developed Nettle (a tea set), with the aim to provide opportunities for social interactions for older people. By pouring boiled water into the pot, users indicate that they are available to talk. The call connection is made by removing the mug's lid and placing it in a recessed place. To end a call, users simply remove the lid from the base to put it back on the mug. StoryBox was implemented by Wallbaum et al. (2018) to support grandparents and grandchildren's daily story sharing over a distance. Objects are placed in the StoryBox, and they can choose to write on the glass pane or record voice messages to tell the story.

2.3 Older people and ICT

2.3.1 Attitudes and behavior

Older people are diverse and possess their own attitudes and behavior when it comes to the use of ICT (Bong & Chen, 2019; Hallewell Haslwanter et al., 2018). In a study conducted by Hallewell Haslwanter et al. (2018) to identify key factors in the engineering process influencing older people's acceptance and use of systems, the diversity among older people as a user group is identified as an important and relevant factor. Older people's characteristics can range from having disabilities and a variety of assistive and accessibility needs to being healthy and having none of these needs, as well as from living alone to living with a partner

(Hallewell Haslwanter et al., 2018; Hansen & Slagsvold, 2016). In this section, older people's attitudes and behavior regarding ICT use are discussed in general using social cognitive theory.

Social cognitive theory has been providing insights into individuals' behavior in using ICT (D. Compeau, Higgins, & Huff, 1999; D. R. Compeau & Higgins, 1995; Lam & Lee, 2005). This theory emphasizes that human motivation and action are extensively regulated by forethought, and this anticipatory control mechanism involves expectations that might refer to the outcomes of undertaking a specific action (Luszczynska & Schwarzer, 2005). Human motivation and behavior are strongly associated with an individual's 'willingness' to learn and use new technology, and older people have their own reasons to use or not to use technology (Neves & Amaro, 2012).

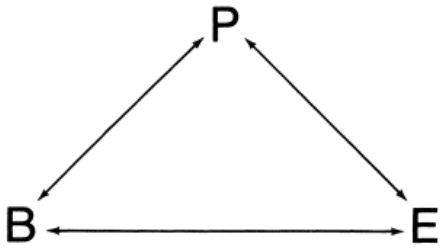

Figure 3. Schematization of the relationships among behavior (B), cognitive and other personal factors (P), and the external environment (E).

The behavior (B) of an individual, which refers to an older person in this dissertation, depends on his or her environment, as well as cognitive and other personal factors (Wood & Bandura, 1989) (refer Figure 3). Lacking functional literacy in ICT is the main cognitive and personal factor (P) influencing older people being unable to utilize ICT. Neves and Amaro (2012) identified a few factors that contribute to the low usage of ICT by older people in Lisbon. The factors include a lack of functional literacy in ICT, which is associated with their educational background and lack of necessity, as they felt that they could live well without the use of ICT, and problems of accessibility and usability. Zickuhr and Madden (2016)'s findings are similar. Among older people aged 76 and above who do not use ICT, 68% expressed their lack of confidence in using ICT. Thirty-eight percent perceived the use of ICT as not relevant to them and, therefore, were simply not interested. However, when older people's ICT skills improve, they are more likely to use ICT and do so more often (Lam & Lee, 2005).

The perceived relevance of using ICT relates to older people's external environment (E). According to Neves and Amaro (2012), in their study of 500 older people, almost half of them did not see the need for using the Internet. However, family and friends are the main reasons why older people use a mobile phone, as 40.2% use mobile phones to talk to family, while 24.9% use them to talk to friends. Older people who are not benefitting from the potential of ICT might suffer from being socially isolated and feel lonely. This is discussed in detail in Section 2.4.

The lack of necessity, accessibility, and usability issues in using ICT can contribute to a 'discouraging' environment for older users in terms of ICT usage. In a study of 10,1888 households, Dascălu, Rodideal, and Popa (2018) reported that Romanians, on average, do not view the Internet as useful, and 31% of them do not have Internet access. Internet access was not a necessity for them, especially when it was also considered expensive. Many studies have shown that ICT designed today is not accessible and usable to older people (Bong & Chen, 2015; Teixeira et al., 2012). In a study of older people's use of mobile instant messaging, Bong and Chen (2015) identified a few accessibility and usability issues in the existing apps: the touch buttons are too small, and the icons are confusing, overly complicated, and not intuitive. Teixeira et al. (2012) compared their improved prototype with Windows Live Messenger and Facebook and drew the conclusion that Windows Live Messenger and Facebook are less accessible and usable. When older users face accessibility and usability problems in using ICT, they will most likely be discouraged.

Another important principle of social cognitive theory is that people are most likely to adopt modeled strategies if the strategies produce valued outcomes (Wood & Bandura, 1989). ICT could potentially have a positive impact on older people's social lives if their challenges in using ICT can be overcome. One of the positive outcomes is tackling older people's social isolation (Y.-R. R. Chen & Schulz, 2016). When older people feel less lonely, their quality of life can improve. This expected outcome results from their perceived self-efficacy. A Bandura (1997, p. 37) defined self-efficacy as "what you believe you can do with what you have under a variety of circumstances," and it concerns about people's beliefs in their capabilities to mobilize the motivation, cognitive resources, and courses of action needed to exercise control over events in their lives (Wood & Bandura, 1989).

2.3.2 Technology acceptance

While addressing older people's use of ICT, their technology acceptance plays an important role. A review of older people's technology acceptance found that the TAM is useful (K. Chen & Chan, 2011). However, a better understanding is required as older people have their own biophysical and psychosocial characteristics, abilities, and challenges related to their acceptance and use to ICT. The TAM used for this dissertation is presented in Article III. Eight determinants were identified as related to technology acceptance for older people's use of the TUI application: (i) perceived usefulness, (ii) perceived ease of use, (iii) perceived enjoyment, (iv) intention of use, (v) actual use, (vi) compatibility, (vii) attitude, and (viii) self-efficacy. In this section, older people's technology acceptance is described as the acceptance of ICT in general.

Perceived usefulness is defined by Davis et al. (1989, p. 985) as "the prospective user's objective probability that using a specific application system will increase his or her job performance within an organizational context.' Many studies have focused on perceived usefulness as a factor affecting older people's technology acceptance (Chiu et al., 2016; Dogruel, Joeckel, & Bowman, 2015; Hsiao & Tang, 2015; Lekjaroen et al., 2016; Mostaghel & Oghazi, 2017). In a study examining older people's acceptance of technology tools in Sweden, Mostaghel and Oghazi (2017) suggested that self-efficacy and anxiety in gerontechnology, an inter- and multidisciplinary field combining gerontology and technology (L. Fozard, 2000), are core conditions in older people's perceived usefulness. In their study, convenience, improved performance, and effectiveness in daily life and activities are assessed as perceived usefulness. They relate anxiety to an older people's apprehension in using technological tools and hesitation due to the fear of making mistakes, while self-efficacy is considered belief in one's ability to complete a technology-oriented task. The concept of self-efficacy is described in further detail later in the same section.

According to Davis et al. (1989), perceived ease of use is the degree to which the prospective user expects the target system to be free of effort. Same as perceived usefulness, perceived ease of use is adopted in many studies, and there is a significant relationship between these two factors (Chiu et al., 2016; Dogruel et al., 2015; Hsiao & Tang, 2015; Lekjaroen et al., 2016; Mostaghel & Oghazi, 2017) contributing to older people's technology acceptance. Perceived ease of use is identified by Hsiao and Tang (2015) as one of the factors affecting whether older people act on their intention to use mobile healthcare watches. A study

conducted by Dogruel et al. (2015) investigated the use and acceptance of new media entertainment technology among older people found that perceived ease of use is a significant predictor of perceived enjoyment. Since the current project targets improving older people's social interactions, perceived enjoyment is considered an important factor in their technology acceptance.

Davis, Bagozzi, and Warshaw (1992) described enjoyment as the use of a system reflecting personal enjoyment for its own sake. Dogruel et al. (2015) argued that there is a lack of consideration of enjoyment or playfulness as 'intrinsic' influencing factors of the system use. In this research, the use of a TUI application, Tangible Cup, has the potential to enhance older people's social interactions. Additionally, older people are likely to enjoy using technology if they feel that they can handle it. While encouraging them to use the Tangible Cup for social interactions, it is important to ensure that they perceive it as enjoyable, playful, and easy to use. In Dogruel et al. (2015)'s study, when studying perceived enjoyment of new media entertainment technology among older people, they focused on two dimensions: the intention to use and actual use.

According to Fishbein and Ajzen (1975, p. 288), intention to use is defined as "the strength of one's intention to perform a specified behavior." Dogruel et al. (2015) regarded intention to use as future system use in their study. When future system use was utilized as a dependent variable, perceived usefulness was found to have a statistically significant association with the intention to use. However, an older user having the intention to use a technology does not necessarily mean they will do so. In their study, Evans et al. (2014) defined actual use as the frequency of usage by the user. Using a TUI application is new and unfamiliar to many older people. Therefore, in the empirical study, measuring actual use, or how often older participants used the Tangible Cup, was important, as well as whether the Tangible Cup was suitable for them. Both actual use and intention to use were found to have an association with perceived enjoyment in a study experimenting with the use of a conversational robot designed for older people (Heerink, Kröse, Wielinga, & Evers, 2008).

Compatibility is defined as Karahanna, Agarwal, and Angst (2006) as the extent of congruence between new technology and various aspects of the individual and the situation in which the technology will be utilized. Chiu et al. (2016) conducted an eight-week touchscreen mobile device training for 39 older people and concluded that compatibility contributed to meeting the participants' learning needs. Along with perceived usefulness, compatibility was

noted by Chiu et al. (2016) as having significant associations with older people's use of the Internet and associated applications. According to Fishbein and Ajzen (1975, p. 216), the term 'attitude toward use' refers to "an individual's positive or negative feelings (evaluative affect) about performing the target behavior." Most older people have a positive attitude about accepting new technology (Mitzner et al., 2010). However, the technology should be neither inconvenient, unhelpful, nor harmful to their security.

Albert Bandura (1982, p. 122) defined self-efficacy as 'judgments of how well one can execute courses of action required to deal with prospective situations.' Lam and Lee (2005) studied the impact of self-efficacy to novice, older ICT users in Hong Kong on their Internet use. The results showed that when older participants became more adept at using ICT, their self-confidence increased, and they became more engaged when using the Internet. When older people observe or experience the ease of using ICT and its positive effect on their life, its usage can spread among their community, which is undeniably a result of empowerment.

2.3.3 Empowerment and user involvement

The concept of empowerment is referred by Robertson and Minkler (1994) to Miller (1985) as the process by which individuals and communities are enabled to take such power and act effectively in transforming their lives and their environment, given that power is the ability to predict, control, and participate in one's environment. In this Ph.D. research, the empowerment concept is used as an approach to recognize, promote, and enhance older people's ability to meet their own needs, solve their own problems, and mobilize the necessary resources to feel in control of their own lives (Gibson, 1991, p. 359). Older people have the power to decide when and where to use ICT but not always 'how.' Users are typically not involved in designing new ICTs, which poses usability challenges for older people as a user group when their special needs are not addressed effectively (Bong & Chen, 2015; Y.-R. R. Chen & Schulz, 2016).

Empowerment is an outcome when an enhanced sense of self-efficacy occurs as a result of the process (Anderson & Funnell, 2010). Using a questionnaire, Hur (2016) studied the empowerment of 246 older Koreans aged 60–85 through ICT-based activities. The study revealed that various factors, such as ICT skills, complementary skills, and social skills, were not associated with empowerment. It was most likely their level of interest in ICT that determined their psychological empowerment. When attempting to increase older people's

interest in learning and using new technology, it is important to gain a thorough understanding of their behaviors and attitudes, and one of the approaches used to do so is user involvement.

User involvement activities include the provision of information to users, obtaining feedback from them on levels of satisfaction with current services or the desirable characteristics of future ones, developing partnerships with them in decision making, and enabling user control of both problem definition and service delivery (Wistow & Barnes, 1993). Recruiting older people to test and give feedback throughout the design and development process can be seen as a form of empowerment. Older people tend to be more skeptical and afraid of making mistakes when using new technology, but this fear can be addressed by involving them in decision making as it improves their sense of power, control, and self-esteem (Schulz & Nakamoto, 2013).

Uzor, Baillie, and Skelton (2012) empowered older people in their design of fall rehabilitation tools by having them co-designed. Older participants attended workshops that consisted of discussions of past experiences, scenarios and personas, games sessions, and user sketches. Their findings highlight the importance of involving older people in the design process. The feedback and input from older participants were proven to be constructive and valuable.

2.4 Older people's social isolation, loneliness, and living alone

According to Coyle and Dugan (2012), social isolation is the objective lack of relationships and social interaction, whereas loneliness is a subjective, distressing feeling. Cornwell and Waite (2009) studied factors contributing to social isolation, including living alone, having a small social network, infrequent participation in social activities, and feelings of loneliness. Loneliness occurs when individuals are dissatisfied with their social relationships, and this dissatisfaction is due to the difference between what they expect or want and what they actually experience in their social lives (Russell, Cutrona, McRae, & Gomez, 2012). As these people's emotional state arises from the subjective perception that their social relationships are deficient either quantitatively or qualitatively, they perceive their social relationships as inadequate and, thus, suffer fromwhich is loneliness (Perlman & Peplau, 1981).

Using Bjørn (2016) six elements that help differentiate between disease, illness, and sickness, we can see that loneliness is an illness rather than a disease or sickness. First, when a person

feels lonely, it is a personal, unpleasant feeling. Second, loneliness is a first-person, subjective, and negative experience involving suffering and pain. When a person feels lonely, he or she feels the pain of not having sufficient social contact. Third, loneliness can be assessed through introspection, intuition (i.e., phenomenology), interaction (i.e., language), and mental states (i.e., psychology). A person feels lonely after he or she has the self-reflection or self-realization that his or her social life is not as good as desired. Fourth, loneliness is considered subjective because it involves self-reflection and self-realization. A person who does not have a high expectancy of a social life tends not to feel lonely as the individual's actual social life is close to the desired one. Fifth, loneliness can be cured via an altruistic approach. Finally, loneliness can involve receiving less attention and support, making moral and social excuses, and reduced accountability. A person's loneliness can result in seeking attention from other people. Thus, others might show more care and support to help a person experiencing feelings of loneliness.

Previous studies have demonstrated a robust association between social relationships and health (Berkman & Glass, 2000; Berkman & Syme, 1979; S. Cohen, 2004; Holt-Lunstad, Smith, & Layton, 2010; House, Landis, & Umberson, 1988; Sabin, 1993; Tomaka et al., 2006). Individuals who perceive themselves as being more socially active and having larger social networks and participations tend to have better health outcomes. Loneliness is seen as a biopsychosocial stressor that is prevalent in adults with heart disease, hypertension, stroke, and lung disease, which are undeniably significant (Petitte et al., 2015). A systematic literature review conducted by Petitte et al. (2015) identified 35 articles that measure loneliness in populations experiencing chronic illness: heart disease (15 articles), stroke (10 articles), obesity (7 articles), diabetes (3 articles), and pulmonary problems (3 articles). These studies were conducted in the United States (13 studies), the Netherlands (5 studies), Sweden (4 studies), the United Kingdom (3 studies), Israel (2 studies), and in Turkey, Malaysia, Ireland, Canada, Greece, Finland, Norway, and South America, only 1 study was conducted. They commented that the diverse study locations are a good indicator for their review. Thus, the link between loneliness and chronic disease should be seen as a global phenomenon and taken seriously.

When older people live alone, it can contribute to a loss of social support and, thus, feelings of social isolation (Jennifer Yeh & Lo, 2004). Older people who both live alone and feel socially isolated and lonely have higher risks of poor self-rated health, two or more chronic conditions, and depression (Smith & Victor, 2019). According to Abell and Steptoe (2019),

there are many reasons older people live alone. For instance, a personal choice or preference when one gets older, a wish to be independent and solitary, being divorced or widowed, and a personal choice or preference when one has a physical or mental health problem that causes difficulty in establishing stable personal relationships or cohabitation. However, living alone does not mean that they are certainly socially isolated and feel lonely. Smith and Victor (2019)'s study identified older people who live alone but do not feel lonely. Thus, in this dissertation, the target is older people who are living alone. No indicators of loneliness and social isolation were collected while recruiting participants for the empirical study.

2.5 Older people's quality of life

As stated by the Gerontological Society of America in a conference in 1955, the challenge of successful aging is about adding life to years, not just more years to life (Roberts & Adams, 2018). For older people, therefore, it is important to have a good quality of life as they live longer. The concept of older people's quality of life are discussed in Articles III and IV. By studying older people's responses regarding the positive things that contributed to their quality of life and negative things that took quality away from their lives, Bowling (2009) developed the OPQOL questionnaire. The OPQOL was conceptually grounded in lay views from the baseline quality of life survey and integrated with theory from a synthesis of the literature. It was then further assessed for interpretation. This questionnaire is used in Articles III (see Section 2.4.2 of Article III).

In this section, more research related to social interaction and quality of life are discussed. In a review studying the relationships between social and leisure activities and the well-being of older people, Adams, Leibbrandt, and Moon (2011) concluded that older people who have more active social lives and participation tend to have better emotional health and quality of life. They assumed that social activities and interactions may reduce the risk of social isolation and supply emotional intimacy, socio-emotional support, reinforcement of one's self-concept and social roles, and the sense of being valued. This assumption supports the findings indicating social interactions, such as social relationships, the enjoyment of meaningful activities, and social integration within communities, can help improve both health and quality of life (Berkman & Glass, 2000; Kane, 2001; CR Victor & Scharf, 2005). However, it is worth mentioning that providing social support was also noted to have a more positive impacts on the well-being of older people than receiving social support, except when the support was received from a spouse or sibling (Thomas, 2009). In terms of social

interaction, older people might feel more meaningful if they could play the role of being independent, useful, and helpful to others.

Older people that are not socially active and feel lonely might have a poor quality of life (Gerino, Rollè, Sechi, & Brustia, 2017; Scocco & Nassuato, 2017; Laurie A. Theeke & Jennifer Mallow, 2013). The quality of life scale developed by Flanagan (1978) covers five conceptual categories, and is reflected to make associations with loneliness. These five conceptual categories are (i) material and physical well-being; (ii) relationships with other people; (iii) social, community, and civic activities; (iv) personal development and fulfillment; and (v) recreation. Each of these conceptual categories has a different scale item. Except for material and physical well-being, all these conceptual categories have a direct link with loneliness and social isolation. In terms of relationships with other people, loneliness happens when one's need for social interaction is not met. Relationships with other people play a vital role in one's social life. Social, community, and civic activities can satisfy the expectation of a person in terms of his or her social life. A person's personal development and fulfillment are partially built upon his or her social life. Last but not least, recreation is important in one's social life, especially as it relates to socializing and group recreational activities.

Laurie A Theeke and Jennifer Mallow (2013) conducted a study using the CASP-12 quality of life scale and found that higher loneliness scores were associated with lower quality of life scores. This indicates that although loneliness can be perceived subjectively, it still has a strong tendency to be perceived as a negative feeling by individuals. Feelings of loneliness and social isolation are associated with health-related quality of life (Bowling, 2014, pp. 45-71), as they are also associated with one's emotional well-being (i.e., life satisfaction), psychological well-being (i.e., anxiety and depression), social well-being (i.e., community integration and functioning in social roles) and physical well-being (i.e., physical health status and physical functioning). Active social networks can help older people minimize feelings of loneliness and maintain an overall good quality of life, health, and physical functioning (Author3, 2016; Berkman & Glass, 2000).

2.6 Summary of the background and conceptual framework

To summarize the background of this dissertation, older people's quality of life is related to two main aspects: their use of ICT and their social relationships and participation. Their

diversity in attitudes and behavior in using ICT shall be kept in mind, but there are general characteristics of older people's use of ICT that should be considered when designing and developing ICT for them. As suggested by Hallewell Haslwanter et al. (2018), older people should be included as early as possible in the project to identify their needs. This guided the methodology in the design and development of the TUI application, as presented in Section 5.1. ICT can enhance social interaction and, hence, social relationships and participation. ICT can be helpful in eliminating social isolation and loneliness, and it should be useful, easy to use, enjoyable, and compatible with older people's daily life. These are the factors affecting older people's technology acceptance (Section 2.3.2). Figure 4 illustrates an overview of the conceptual framework adopted for this interdisciplinary research, which was generated based on the summary of the background.

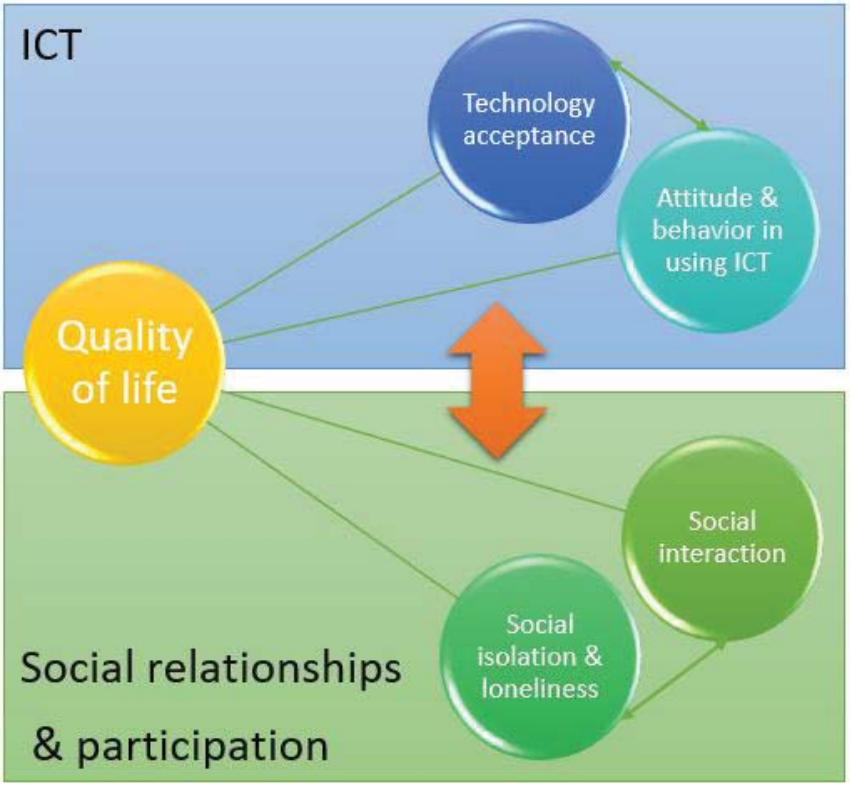

Figure 4. Overview of the Ph.D. research's conceptual framework.

3 Aims and contributions

The main goal of this research is to explore how TUI can impact home-dwelling older people's technology acceptance and quality of life by enhancing their social interactions. The main aims of the study are threefold: (i) study the state of the art of TUI for older people's social interactions and identify the knowledge gaps in this research field, (ii) design and develop a TUI application based on the literature review and older people's needs, and (iii) study the impact of TUI use on older people's technology acceptance, social interactions, and quality of life.

Articles I–IV are a continuous process of the whole Ph.D. research project, undertaken to achieve the main research goal. Figure 5 illustrates the entire research process and the relationships between each article and the main research goal. Table 1 summarizes the research questions of all the articles, their main findings, how they relate to the Ph.D. research process, and their contributions to the research field.

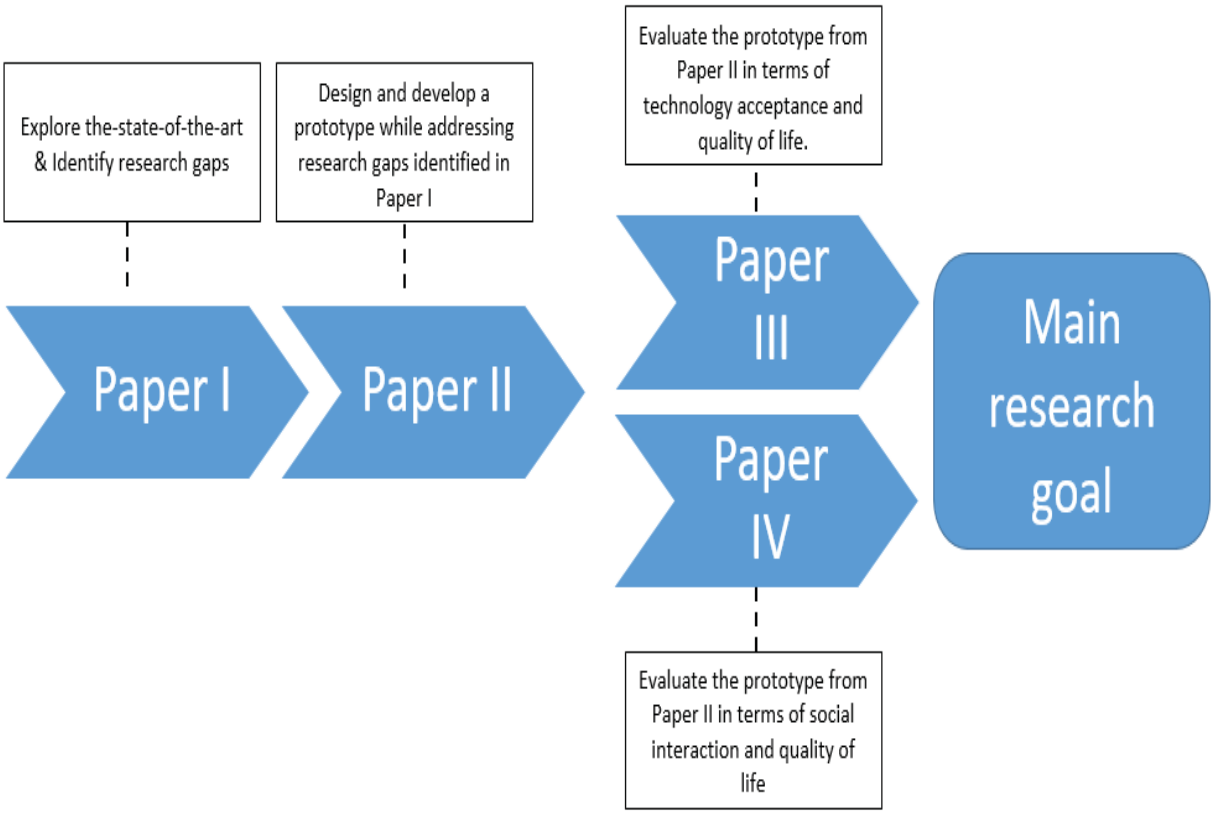

Figure 5. Overview of the research process and how each of the four articles is related to the main research goal.

Table 1. Summary of the research questions and main findings, as well as each paper's contribution and how it relates to the study

	Research questions	Main findings	Relationship to the study	Contributions
Article I: Tangible User Interface for Social Interactions for the Elderly: A Review of Literature	✓ How does TUI impact older people's social interactions? ✓ Have older people been involved in the process of designing and developing TUI applications, and if so, in what way?	✓ Only 21 relevant papers were found. ✓ Most of the papers focus on usability, accessibility, and user experience aspects. ✓ Lack of older users' involvement. ✓ Lack of interdisciplinary collaboration between researchers. ✓ Lack of guidelines for developing and evaluating TUI for older people.	State-of-the-art. ✓ Identify research gaps. ✓ Guide the research design for Articles II, III, and IV.	Provide suggestions for future research on TUI for older people's social interactions.
Article II: Tangible Cup for Elderly Social Interaction:	To develop a TUI to improve older people's social interactions and well-being. While achieving this, we wished to	A list of lessons learned, which can serve as guidelines when designing TUI for and with older people	Design and development of the TUI prototype, Tangible Cup using user-centered design and co-design approach.	Provide lessons learned in designing a TUI prototype focusing on social interactions with and for older people.

Design TUI for & with Elderly	✓ To involve older participants throughout the TUI design and evaluation processes. ✓ To provide guidelines for developing and evaluating TUI for older people.		✓ Followed the suggestions from Article 1 (i.e., involve older people throughout the research process and provide guidelines for developing TUI for older people).	
Article III: Technology Acceptance and Quality of Life among Older People Using a TUI Application	To investigate ✓ The relationship between older people's technology acceptance and quality of life before using the TUI intervention. ✓ Changes in technology acceptance and quality	Quantitative data: ✓ No association observed between older people's technology acceptance and their quality of life before using the TUI intervention. ✓ No statistically significant changes in quality of life after using the TUI intervention.	The impacts of TUI on older people's technology acceptance and quality of life using a mixed of quantitative and qualitative approach. ✓ Provide the fundamental argument on	Demonstrate the potential of TUI by showing its impact on older people's technology acceptance and quality of life, and the association between older people's technology acceptance and quality of life. This

	of life after using the TUI intervention. ✓ The association between changes in technology acceptance and quality of life after using the TUI intervention.	✓ 12 out of 16 participants improved in technology acceptance after using the TUI intervention. ✓ Statistically significant correlations found between the following: ❖ Dimension 5 of OPQOL (home and neighborhood) with overall technology acceptance (TAM), Dimension 2 (perceived ease of use) and Dimension 8 (self-efficacy) of the TAM; ❖ Q of OPQOL (the first question, which assesses participants' overall quality of life) with Dimension 5 (actual use) and Dimension 7 (attitude) of the TAM. ❖ Dimension 4 of the TAM (intention to use) with OPQOL and Dimension 7 of OPQOL (financial circumstances).	relationships between older people using the TUI application with their technology acceptance and quality of life.	can contribute to the implications in using TUI as a more intuitive user interface for technology designers and developers, as well as older people's clinicians and healthcare managers.

		Qualitative data: ✓ The participants were not the Tangible Cup's target user group, and they suggested who the Tangible Cup might be suitable for, as well as how to approach these target users. Two main themes (i.e., 'suitability of the Tangible Cup' and 'potential of the Tangible Cup') were generated.		
Article IV: Exploring tangible user interface for social interaction and quality of life: The experiences of home-	To investigate how home-dwelling older people experience a TUI application with respect to social interaction and quality of life.	Some participants managed to have enjoyable conversations with others despite the challenges in using the Tangible Cup, while the other did not. Three main themes were generated (i.e., reasons to use or not to use the Tangible Cup), and the mismatch between the participants' attitudes and behavior in using ICT and the design of the technology.	The impacts of TUI on older people's social interaction and quality of life using a qualitative approach. ✓ Understand how older people use the TUI application in relation to their	By identifying the characteristics of older people for whom a TUI would be suitable and adopting a design that can facilitate older people's use of TUI, the research may contribute to improved strategies for policymakers, educators,

dwelling older adults			social interactions and quality of life.	clinicians, future researchers, and older adults.

To summarize the contributions of this interdisciplinary Ph.D. research, the research adds new knowledge regarding TUI's potential for improving older people's technology acceptance, social interactions, and quality of life. This new knowledge has practical implications for designers and developers, clinicians and practitioners, policymakers, researchers, and older people. Designers and developers should consider integrating TUI into older people's daily life and their diversity when designing TUI for them. To ensure that the TUI design is suitable for older people, older people should be involved throughout the whole process, from designing to evaluating the prototype. Other potential stakeholders, such as clinicians and practitioners should also be involved in designing and evaluating the prototype as well. Older users who utilize their services tend to trust and have faith in them. The findings of this research can hopefully instill positive attitudes toward using ICT among these clinicians and practitioners. For researchers and policymakers, this research provides research design considerations for implementing and evaluating TUI from the perspective of technology acceptance, social interactions, and quality of life over a long period time frame. Finally, older people can be more aware of the potential of using TUI applications or ICT in general. It is hoped that the results of this research will encourage them to be more positive toward accepting and using ICT.

4 Systematic literature review

A systematic literature review (Article I) was conducted to study the state-of-the-art in TUI for older people's social interactions.

4.1 Method

To develop our review methodology, we referenced previously published literature reviews and systematic literature review guidelines by Keele (2007). Our review methodology consisted of three main phases: (i) planning the review, (ii) conducting the review, and (iii) studying the selected publications and reporting the result. We identified the needs of this review and generated the research questions while planning the review.

During the review phase, the main search terms were identified, and inclusion criteria and exclusion criteria were defined. These three were combined to generate the search string. The three search terms were 'elderly,' 'tangible user interface,' and 'social.' The inclusion and exclusion criteria were as follows:

1. The target group of the paper must be people age 50 or older.
2. The paper must focus on TUI.
3. The paper must focus on the social aspect of TUI use.
4. Papers where TUI focuses on robot, mobile, computer and tablet-based applications, ambient intelligence and smart homes are excluded. Our primary focus on TUI is using everyday objects and not whole environments or unfamiliar objects. Unlike TUI applications, robots, mobile devices, computers, tablet-based applications, ambient intelligence, and smart homes do not fulfill the condition of using an everyday object. Touch screen devices, such as tablets and smartphones, use a traditional GUI, so they still require older users to interact with electronic devices through graphics and icons instead of a physical item. Older people tend to have some difficulty using mobile phones, computers, and tablets, and both ambient intelligence and smart homes work as an environment and not a single object. Therefore, they are also excluded.
5. Only published or peer-reviewed works are included. Dissertations and theses are excluded.
6. Non-English language papers are excluded.

The generated search string was *elderly AND 'tangible user interface' AND social AND NOT robot AND NOT 'smart home' AND NOT 'ambient intelligence.'* We conducted the search using the generated search string on five electronic databases (i.e., ACM, Science Direct, Engineering Village, IEEE, and Google Scholar), as recommended by Brereton, Kitchenham, Budgen, Turner, and Khalil (2007), as well as on Springer, as recommended by Keele (2007).

The search results were first screened to remove duplicates. Then, abstracts were read, and the contents of the papers were screened to exclude papers that did not fulfill all the inclusion criteria. Finally, the full-text version was read to confirm eligibility. Since there was no commonality among the data collected in these studies, we did not perform a quantitative synthesis. The whole process, including the number of search results at each stage, is illustrated in Figure 6. Review criteria were generated based on the research questions in the last phase so that the selected papers could be studied and reviewed based on these criteria.

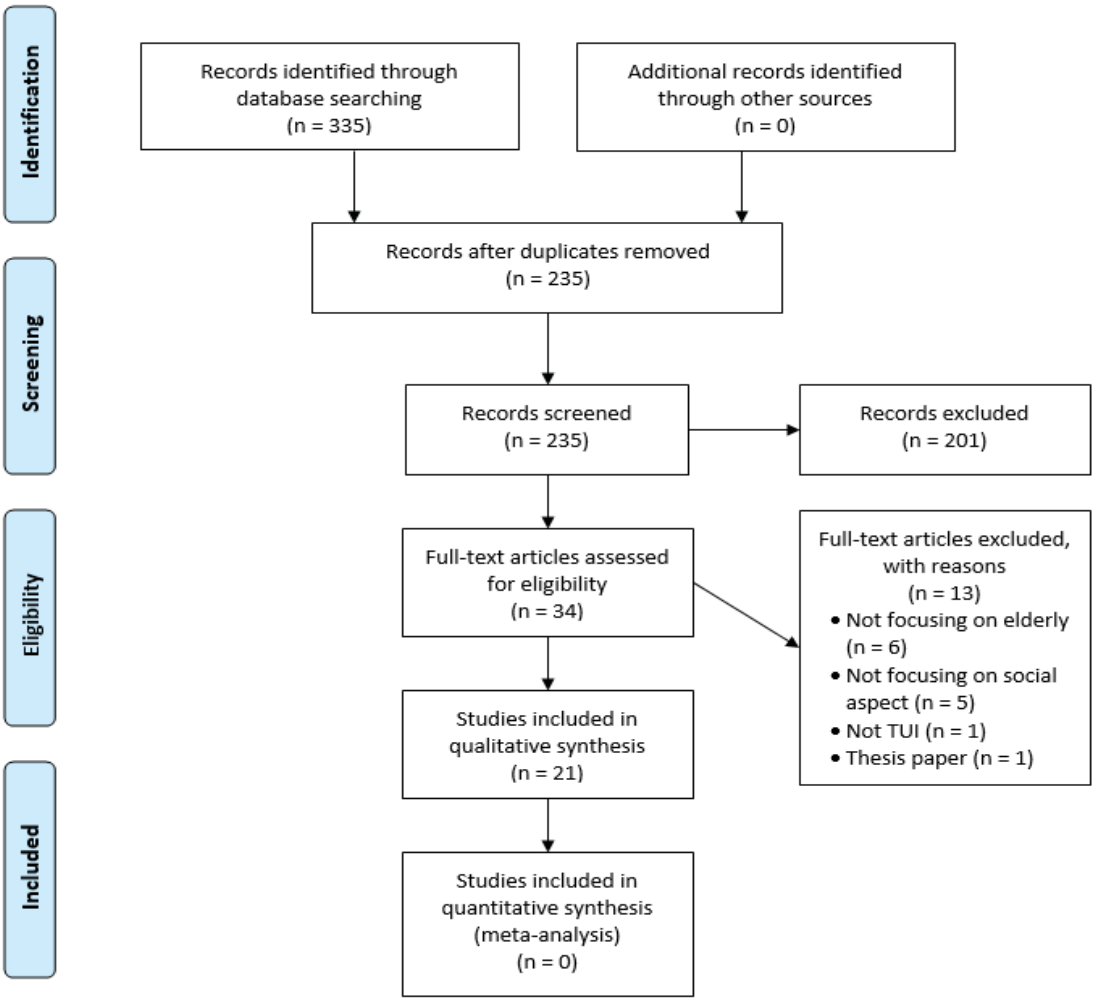

Figure 6 Process of review using a PRISMA flow diagram.

To assess the quality of work of the identified relevant papers and pinpoint knowledge gaps in the state-of-the-art, we studied and reviewed the 21 selected papers using the following criteria. These criteria were generated based on our research questions (see Table 1).

1. Objective of the study.
2. Discipline in which the author and co-authors of the papers worked.
3. Methodology guiding the design and development of the prototype.
4. Methodology guiding the evaluation process.
5. User involvement (i.e., older people's involvement in any stage of the research).
6. Sample size and demographics (during evaluation).
7. Evaluation method and data capture.

4.2 Results

The systematic literature review identified 21 papers related to TUI's impact on older people's social interactions. The low number of relevant papers clearly indicates there has been scant research on this topic. Table 2 in Article I can be referred for a summary of the review of all 21 papers.

In this section, the review's results are presented in two parts. First, a summary of the results analyzed based on the above-mentioned criteria are presented:

1. Objective of the study. Most of the papers focused on designing, developing, and evaluating TUI applications, and their aim was to address loneliness and social isolation among older people.
2. Discipline in which the author and co-authors of the papers worked. Most of them worked in the technology field, while a few worked in art and design.
3. Methodology guiding the design and development of the prototype. Minimal user involvement, as only six papers adopted a user-centered approach (Ehrenstrasser & Spreicer, 2013; Foverskov & Binder, 2011; Kern, Stringer, Fitzpatrick, & Schmidt, 2006; Spreicer, Ehrenstrasser, & Tellioğlu, 2012; Tellioğlu, Ehrenstrasser, & Spreicer, 2012; West, Quigley, & Kay, 2007).
4. Methodology guiding the evaluation processes. Twenty papers used an empirical approach.

5. User involvement. (User here means older people. Involvement means involvement at any stage of the research). Minimal user involvement. Only Sarki, Haeun, and Kwon (2015) and Tsai and Chang (2009) involved users in their evaluations.
6. Sample size and demographics (During evaluation). Four papers did not state the sample size and the participants' demographic details. Twelve papers mentioned that the participants were older people.
7. Evaluation method and data capture. Most were focused on usability. Only seven papers studied older participants' social interactions (Angelini et al., 2016; Ehrenstrasser & Spreicer, 2013; Foverskov & Binder, 2011; Huldtgren, Mertl, Vormann, & Geiger, 2017; Marques, Nunes, Silva, & Rodrigues, 2011; Meza-Kubo, Morán, & Rodríguez, 2014; Murko & Kunze, 2015).

The second part includes recommendations based on the first part, and some of them are gaps that need to be addressed so that TUI can facilitate older people's social interactions:

1. Precise use of the term 'tangible user interface.'
2. Older people's user involvement throughout the whole research process.
3. More research on TUI for older people's social interaction.
4. More focus on the social interaction aspect in addition to usability during evaluation.
5. Interdisciplinary collaboration.
6. Longitudinal research to study the impact of TUI on a larger scale.
7. Guidelines for developing and evaluating TUI for older people.

The study design of Articles II, III, and IV is based on these recommendations.

5 Design and development of the TUI intervention

The process of designing and developing the TUI intervention, the Tangible Cup, was summarized and published as Article II. In this chapter, the process is described in detail.

5.1 Methods

As stated in Article II, the aim of the research was to develop a TUI prototype for older participants to improve their social interactions and well-being. To achieve this aim, we adopted a user-centered and co-design approach in designing the TUI prototype, Tangible Cup. User-centered design was chosen due to its advantage in gathering and utilizing valuable input, ensuring end-users will be able to use the end product (Ehrenstrasser & Spreicer, 2013; Foverskov & Binder, 2011; Kern et al., 2006; Meiland et al., 2014; Prior, Arnott, & Dickinson, 2008; Santana et al., 2005; Spreicer et al., 2012; Tellioğlu et al., 2012; Van Veldhoven, Vastenburg, & Keyson, 2008; Vermeulen et al., 2013; West et al., 2007). The co-design approach can ensure the inclusion of older people in decision making and contribute to empowering them through the design process (Göllner, Lindenberg, Conradie, Le, & Sametinger, 2010; Raviselvam, Noonan, & Hölttä-Otto, 2014; Steen, Manschot, & De Koning, 2011).

Guided by a user-centered approach, we conducted a focus group interview and four iterations of design, implementation, and usability testing. Co-design was used heavily in the focus group interview and iteration III. Figure 7 provides an overview of the research process.

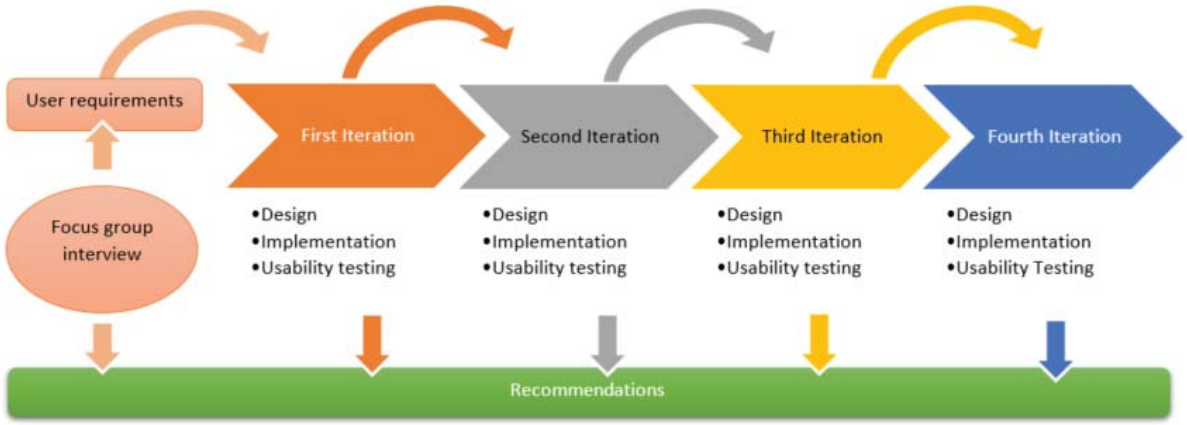

Figure 7. Overview of the research process of design and development of the Tangible Cup.

The identified user requirements were used to define the Tangible Cup's features and functionalities, which were then designed and implemented. Usability testing was then conducted using the developed prototype with two older participants at the end of each iteration. The goal was to test the implemented features and functionalities at an early stage (Lazar, Feng, & Hochheiser, 2010, p. 252). All the usability testing was performed at the participants' homes, which is the most natural setting for them.

During usability testing, the participants were first briefed about the project and the prototype. They were then asked to perform a series of tasks using the prototype, and they were observed while performing them. After usability testing, they were asked about the design and their experience of using the prototype. The comments and feedback from usability testing were taken into account in the next iteration to improve the design. In addition, new features were incorporated into the existing design.

5.2 Recruitment procedure and participants

The plan was to recruit participants for the focus group interviews via a stand at the local senior center. However, the stand did not attract any older visitors. Some visitors were approached, but none of them were interested. After failing to recruit older participants from the senior center, we found three older volunteers (P1–P3) who teach iPad courses and walk-in sessions on ICT use for other older people, as well as a young woman who works as a volunteer and assists them in the courses and sessions. The focus group interview participants' characteristics are summarized in Table 2.

Table 2. Summary of the focus group participants' characteristics

ID#	Age	Gender	Work experience	Years of education
P1	76	M	Management	14
P2	71	M	Computer engineer	20
P3	71	F	Administrative	16
P4	17	F	Currently at upper secondary school. Volunteer in elderly home care services.	12

Participants P1–P3 have considerable experience with using ICT. They are advanced ICT users and want to help other older people improve their ICT skills and knowledge.

The first iteration of usability testing was conducted with two older people (P5 and P6) recruited via the magazine *Pensjonisten* (The Pensioner) (see Appendix I). A total of five older people contacted the researcher, and all of them stated the reasons they were interested in volunteering to participate in the study. They were interested in ICT and had been using ICT for some time. Thus, they were interested in trying out this new ICT tool, "a cup as a communication tool," as mentioned in the magazine. Other participants (P7–P10) were recruited based on networks and previous projects related to older people's use of ICT (Bong & Chen, 2015, 2016). The usability testing participants' characteristics are summarized in Table 3.

Table 3. Summary of the usability testing participants' characteristics

ID#	Age	Gender	Work experience	Years of education	Participation
P5	74	M	Diver	12	Iteration I
P6	74	F	Secretary	14	Iterations I, II, IV
P7	70	F	Finance	15	Iteration II
P8	77	M	Truck driver	8	Iteration III
P9	77	F	Housewife and catering	8	Iteration III
P10	81	M	Academia	19	Iteration IV

Our original target group was older people who have low ICT literacy and feel socially isolated. However, they were difficult to recruit. People who are skeptical about new technology tend to not agree to participate in this type of research.

5.3 Ethical considerations

Since no sensitive data would be collected, and GDPR was not enforceable until after May 2018 (EU, 2018), approval was not required from the *Norsk senter for forskningsdata* (NSD) (in English: Norwegian Centre for Research Data) prior to conducting this study. The

participants were first briefed with written and oral information about the study. Their informed consent was given prior to participating in the study (see Appendix II for the consent form). Once they understood and agreed to participate, they were asked to sign the consent form. All data collected in this study were stored and processed in a physically isolated storage device belonging to the data controller/project leader (i.e., the Ph.D. candidate responsible for the project). The data storage device was not connected to any network.

5.4 Results

5.4.1 Focus group interview

The aim of the focus group interview was to gather user requirements for the Tangible Cup. The focus group interview was conducted at a senior center in Oslo. First, questions related to older people's use of ICT and their social lives were asked. They were then presented the idea of Tangible Cup, along with three real cups in different sizes: a large mug, a medium coffee cup, and a small espresso cup. Blank pieces of paper were given to each participant to draw his or her own design of a Tangible Cup (see Figure 8). The discussion continued while they were drawing so that they could improve their design as they were talking.

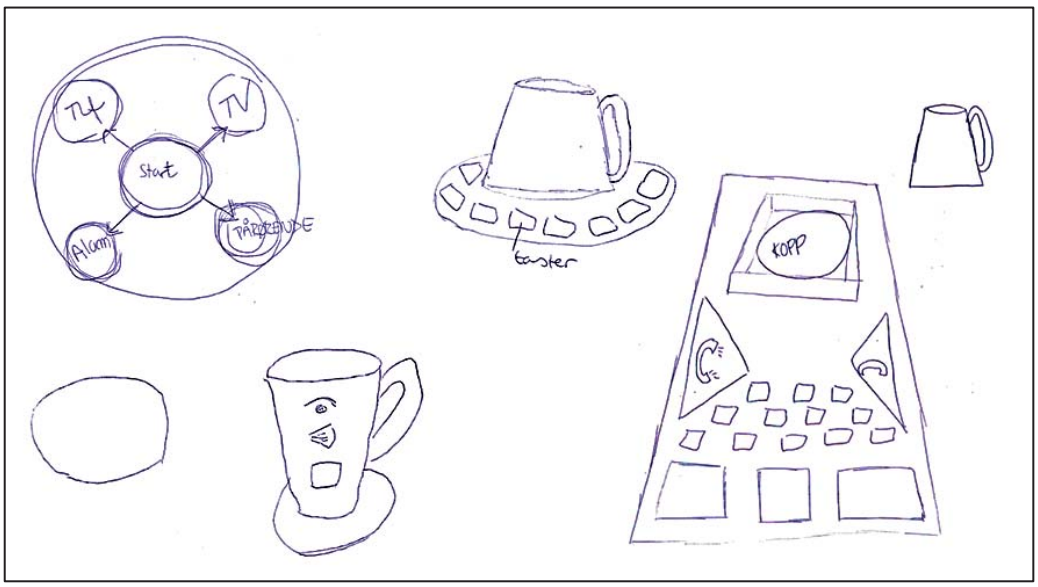

Figure 8. Drawings of Tangible Cup designs made by the focus group interview participants.

The following summarizes the outcomes of the focus group interview in terms of design considerations. As for the size and shape of the cup, they recommended using a typical medium-sized coffee cup as it aligns most closely with the Norwegian coffee-drinking

culture. They also recommended including a large, strong handle which users could place their fingers into it and lift the cup. It had to be light so that older users had no problem lifting it. They agreed that the cup might be too complicated for most older people as older users tend to have problems with small buttons and 'confined' user interfaces for interactions. This was why the Tangible Cup's design was extended from just a cup to a few designs that paired the Tangible Cup with a saucer with buttons (see Figure 8). They all agreed the functionalities should be kept to a minimum, and the interface should not have too many choices. Finally, it had to be dishwasher-safe, and the interface for interactions should be waterproof as older users might spill coffee on it.

5.4.2 Iterations

Based on input from the focus group interview, the first iteration produced a low fidelity prototype using a table mat and a cup (see Figure 9).

Figure 9. Tangible Cup prototype in iteration I.

The Tangible Cup's design was extended from just a cup to including a table mat as an interaction interface, as it would be easier for older people to interact with a larger interface, reducing their fear of making a mistake. On the table mat, four oval callouts with people's names and two buttons, 'start call' and 'end call' buttons were pasted. The oval callouts represented people who were using the Tangible Cup. A regular coffee cup was used as a

control to interact with the table mat and perform tasks during testing. Functionality was kept to the minimal, which was only to have audio conversations.

The participants in this iteration, P5 and P6, had experience with using smartphones and tablets. P6 had used computers since 1992 and still used one daily. Both of them were interested in new technology and could be considered advanced ICT users. During testing, they were told to use their cup at home to interact with the table mat provided. The tasks given to them were making a call to someone, receiving a call from someone, and engaging in conversations with these people. The tasks were performed using the cup and table mat.

At the beginning of testing, they could not understand the need for using a cup as a communication tool since they were already adept at using a smartphone. The purpose of adopting TUI for older people who are socially excluded due to having low ICT literacy was then explained to them. After this was explained to them, the testing was performed successfully, and interviews were conducted. A few usability issues were observed during usability testing and pointed out during the interviews:

1. Both testers reportedly preferred the table mat to display fewer names so that users would not have to look at every single ‘button’ when searching for a particular contact.
2. They agreed that there should only be one table mat with buttons, but more cups should be able to be used with the table mat as they need to be washed after use.
3. The table mat was too big and difficult to carry around by older users. Older people do not use their cups and drink coffee in one spot. They tend to walk around and, for example, move from the kitchen to the living room to watch television when drinking coffee or move to an outdoor garden when the weather is nice during the summer.

In addition to usability issues with the Tangible Cup, the suitability of different kinds of older people using it was addressed during testing. Due to the diverse characteristics of older users, such as their careers prior to retirement, race, ethnicity, educational background, and culture, the participants commented that the Tangible Cup is more suitable for older people who live alone and have low ICT literacy.

Figure 10. Tangible Cup prototype in iteration II.

Comments from participants in the usability testing of iteration I were taken into account, and instead of using table mat, cup coasters were used to resolve the 'immobility' issue of a table mat in iteration II. Four cup coasters were used for interactions between the cup and a tablet: 'log in,' 'start call,' 'end call,' and 'search contacts' (see Figure 10). A tablet was used to display actions of the user and other users.

The testing tasks included logging in, recognizing someone who has just logged in, calling that person, ending the conversation, receiving a call from another person, and finding others who are logged on at the same time. When the user and other users logged in, the sound of pouring coffee was played from the tablet. A ringing sound was played when the user called someone or received a call. The concept of the Wizard of OZ experiment (Kelley, 1984) was adopted. While older participants performed the tasks using a cup, actions displayed on the tablet were manipulated from a computer. The participants were made to believe that their interactions with the cup and cup coasters actually triggered the actions on the tablet.

This iteration's usability testing involved one existing tester from the previous iteration (P6) and a newly recruited tester (P7). P6, who was an advanced ICT user, still did not understand the use of a Tangible Cup for social interaction. P7 faced the same problem. However, after explaining to them that the Tangible Cup uses TUI, which could offer more intuitive

interactions for older people with lower ICT literacy, they understood the design and proceeded with the testing.

When P6 first heard about the idea of a Tangible Cup, she thought it would be a cup with buttons integrated into it. Users could initiate interactions by pressing buttons on the cup. However, she also voiced some concern about needing to turn the cup around to find the right buttons for a specific task. P6 commented that a Tangible Cup could be suitable for some of her friends, who were around her age, as they had low ICT literacy and were skeptical about using new ICT.

Overall, both P6 and P7 performed all the testing tasks smoothly. This shows that the Tangible Cup was generally easy to understand and use. A few usability issues and recommendations were gathered in this iteration of testing:

1. The symbol on the '*search contacts*' coaster was confusing to both P6 and P7. P6 suggested using a symbol with multiple blank avatars instead.
2. There was no '*log out*' coaster. P6 and P7 suggested including a '*log out*' cup coaster.
3. Since the cup was used with a tablet to display interactions, P6 suggested that video chat could be done instead of just voice chat.
4. P6 and P7 were confused when the upcoming action required users to use the same coaster as the previous action.
5. In terms of sounds played when interacting with the cup coasters, P7 was not bothered by them, while P6 thought the ringing sound was too sharp. She suggested a preferred melody could replace the sharp ringing sound, which is a personalized feature and will be implemented in the future. P6 also found the pouring coffee sound interesting, as it indicated someone logged in.

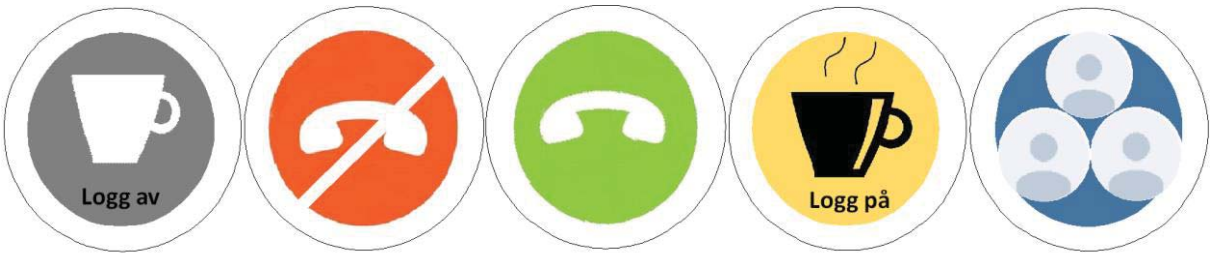

Figure 11. The design of coasters in iteration III (From left to right: *log out*, *end call*, *start call*, *log in,* and *search contacts*).

In the third iteration, we modified the design of the cup coasters, and a *log out* coaster was added to the prototype (see Figure 11). The design of the *end call* coaster was modified so that it could be differentiated from the *call* coaster not only by its color but also its symbol. The Symbol showing coffee in the coffee cup indicates *log in*, while an empty coffee cup symbol indicates *log out*. Lastly, the *search contacts* coaster's symbol is a group of blank avatars.

One testing task was added in this iteration, which was logging out from using Tangible Cup. The testing went smoother for P8 than P9. P8 owned a smartphone and had more experience using mobile applications, while P9 had only used an old Nokia phone that could only be used for calls and messages. P9 did not have much experience with or knowledge about using the Internet and ICT. She was a full-time housewife when her kids were young, and her work experience involved cooking food at a restaurant. When the Tangible Cup was presented, both of them were confused. They did not understand how a Tangible Cup with coasters could work as an ICT tool.

However, they did manage to complete most of the assigned tasks. P9 had problems understanding certain terms such, as 'log in' and 'log out.' Some explanations were required during her testing. P9 also problem understanding avatar and conversation icons (see Figure 12) on the application.

Figure 12. Avatar and conversation icons in the Tangible Cup application in iteration III.

Iteration III's usability testing revealed two similar issues from the previous iteration. First, there was some confusion when the upcoming action required users to utilize the same coaster as the previous action. When the Tangible Cup was placed on the *end call* coaster, and calls had to be rejected using the same *end call* coaster, they were expected to lift the cup and place

it down again on the same cup coaster to trigger the reject call action. However, both P8 and P9 did not move the Tangible Cup. They thought they could reject a call without moving the Tangible Cup because it was already on the *end call* coaster.

Second, participants experienced some difficulty understanding the *search contacts* coaster. P9 did not understand the icon's avatar, so she did not understand the design of putting three avatars together. P8 and P9 agreed that the design would make more sense if the avatars were more human-like and in different colors.

During the interview, they were also asked to co-design the cup attachment. The aim of developing a cup attachment was to incorporate a radio frequency identification (RFID) reader. RFID tags on the cup coasters would be read by the RFID reader built into or on the cup attachment. By simply attaching a cup attachment, older users could use any cup they wanted as a Tangible Cup. The idea of the cup attachment was explained to P8 and P9, and then their ideas about the design of a cup attachment were discussed. They looked around at items in their summer cabin while brainstorming. By the end of the discussion, they suggested the design of the cup attachment could function like a round fridge magnet that can be attached to the bottom of the cup.

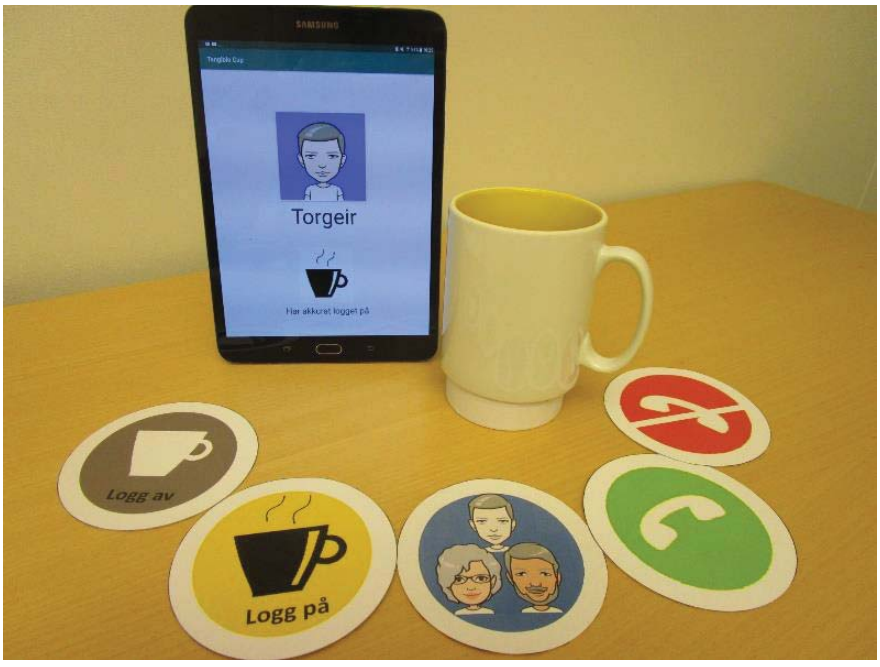

Figure 13. Tangible Cup prototype in iteration IV.

In iteration IV, a cup attachment was added to the entire set of Tangible Cup, and the icon on the *search contacts* coaster was modified to three human-like avatars (see Figure 13).

First, the researcher explained the cup attachment, as well as how to attach it to the cup, were explained to P6 and P10. They were then asked to perform the same test tasks as in the third iteration.

P6 and P10 completed all the tasks without much effort. P10, who had never tested the Tangible Cup, could understand how to use the Tangible Cup and the design of the cup attachment and coasters, just like P6 had. Both of them thought that the idea of using the cup attachment on any cup and the Tangible Cup to communicate with the calling application on the tablet was useful.

5.4.3 Reflection after the whole process

The table below summarizes the feedback and recommendations gathered during the focus group and four iterations of design, implementation, and usability testing. Reflection was undertaken to generate a list of lessons learned, which are presented in Article II.

Table 4. A summary of feedback and recommendations gathered in Article II

	Feedback and recommendations	A list of lessons learned
Focus group interview	***Size and shape***. A typical medium-sized coffee cup.	Use familiar physical objects and integrate the TUI into daily life.
	Weight. Lightweight with a large, strong handle that users can easily hold with their fingers to lift it.	Consider older people's physical abilities.
	Design. The Tangible Cup is small. Thus, it can be too complex and crowded with all the functionalities integrated into it. The design of a saucer with buttons is suggested to avoid having too many buttons on the cup itself (see Figure 8).	Avoid crowded interfaces, provide necessary instructions, and ensure practicality.
	Functionality. Minimal, with few options on the interface.	Minimal functionality and avoid crowded interfaces.

	Dishwater safe and waterproof.	Consider older people's physical abilities, integration of the TUI into daily life, and ensure practicality.
Usability testing of the first iteration	***Mobility issue***. The table mat was too big to carry around. Participants suggested cup coasters.	Integration of the TUI into daily life and ensure practicality.
	Interface issue. Too many names on the table mat.	Avoid crowded interfaces.
Usability testing of the second iteration	The symbol on the *search contacts* coaster was confusing.	Integration of the TUI into daily life.
	Confusing when an upcoming action required users to use the same coaster as the previous action.	Provide necessary instructions.
Usability testing of the third iteration	The symbol on the *search contacts* coaster was confusing. Tester was not familiar with the avatar symbol.	Integration of the TUI into daily life.
	Confusing when an upcoming action required users to use the same coaster as for the previous action.	Provide necessary instructions.
	Fridge magnet-inspired cup attachment. The outcome of the co-design can be easily attached to the bottom of any cup.	Integration of the TUI into daily life, ensure practicality, and use of familiar physical objects.
Usability testing of the fourth iteration	Participants understood and performed all the tasks easily.	

In addition to the list of lessons learned that could serve as design guidelines, another list of lessons learned was compiled based on the experience of dealing with older participants throughout the entire design and testing process. This list of lessons learned can be used as a reference when involving older people in the process of designing a TUI or even designing ICT for them in general.

1. ***Use of actual objects to demonstrate.*** TUI was a new idea for older participants involved in the study. Thus, the use of actual objects helped them understand the concepts.
2. ***Choice of words.*** It was observed that some ICT jargon, such as log in, log out, and messenger, might be unfamiliar to older people who are novice ICT users.
3. ***Find the most natural setting.*** Conducting usability testing at the participants' homes seemingly allowed them to be more relaxed and relate more to their prior experience with ICT than those in the focus group sessions conducted at the senior center.
4. ***Motivation and encouragement.*** The older ICT users, especially those who were novice ICT users, appeared to be afraid of providing 'wrong' feedback or suggestions. It was, therefore, important to motivate and encourage them throughout the process.
5. ***Consider the diversity of older people.*** All the participants involved in the focus group interview and usability testing, as well as other older people who were approached and asked to participate in the study, were a diverse user group.
6. ***Involve older users as early as possible.*** The involvement of older people as early as the brainstorming and design stage proved to be essential, as the participants provided ideas and feedback that were markedly different from the initial idea of the Tangible Cup in the proposal. This is further reflected in Section 7.2.1.

5.4.4 Tangible Cup

The final outcome is the fourth iteration of the Tangible Cup, which was used in the empirical study. It is briefly presented in Section 2.3 of Article III and the Tangible Cup section of Article IV. In this section, the Tangible Cup is described in detail. In Figure 13, the components of the Tangible Cup are illustrated. It consists of a cup attachment (under the cup), five cup coasters (from left to right: *log out, log in, search contacts, call* and *end call*) and a tablet. There are RFID tags attached under all cup coasters, and a RFID reader is placed inside the cup attachment. By placing the cup attachment on the cup coasters, the RFID reader

inside the cup attachment will read the RFID tag number on the cup coasters. This reading process will inform the calling application installed inside the tablet of the action to be performed.

The functionalities of each cup coaster are described below. The *log in* coaster is used to start the calling application and log the user in (see Figure 14), while the *log out coaster* is used to log the user out from the application and close the application in the tablet. Using the *search contacts* coaster will navigate the user from the log in screen to the contact list screen (see Figure 15).

Figure 14. Log in screen in the Tangible Cup's calling application.

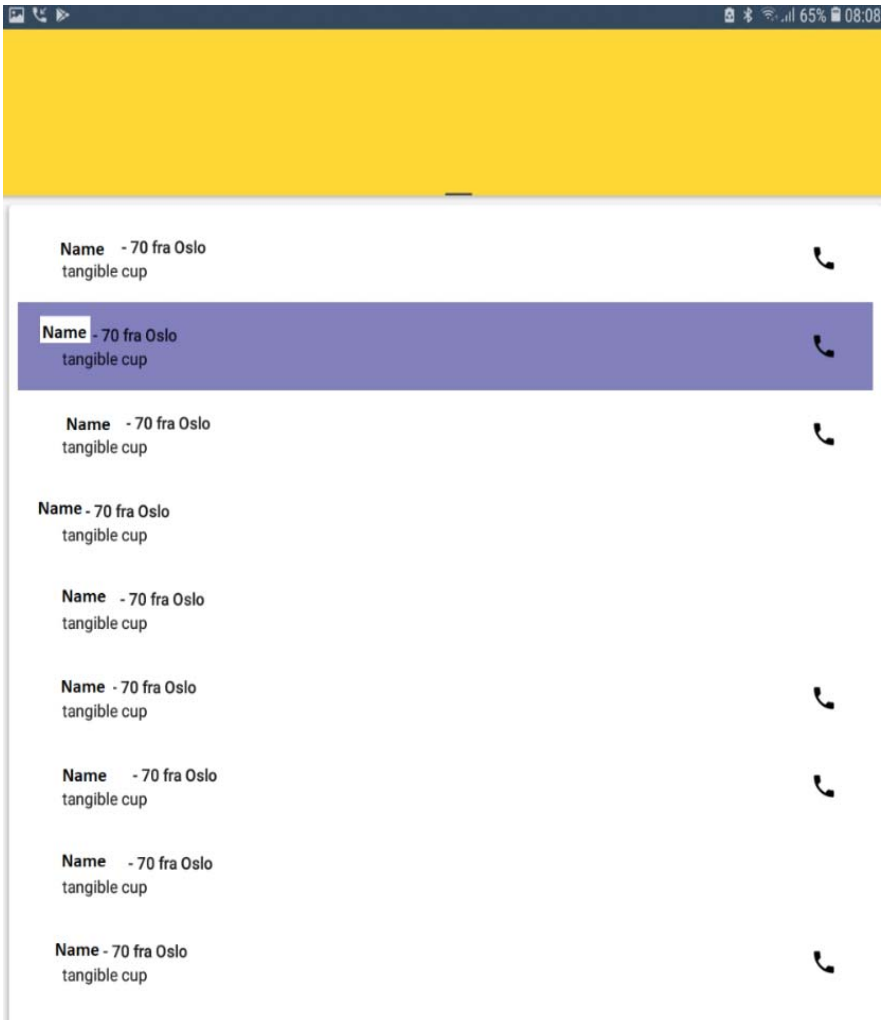

Figure 15. Contact list screen in the Tangible Cup's calling application.

A contact's information includes his or her name, age, city, and status. The phone symbol at the end of the contact information indicates that the user is logged in. As shown in Figure 15, one contact is highlighted, and this highlighting (in purple) at the particular contact stays on for approximately 7–8 seconds. Within these 7–8 seconds, the caller can place the cup attachment on the *call* coaster to make a call to the highlighted contact. After the highlighted contact has received the call, he or she can choose to use the *call* coaster to accept the call or the *end call* coaster to reject the call. Another function of the *end call* coaster is to end the conversation and hang up the call. After using Tangible Cup, the user must use the *log out* coaster to exit the application. Otherwise, the application will still be running in the background, and their status will remain 'logged in.'

6 Empirical study

In this chapter, the empirical study, which contributes to Article III and IV, is presented. The empirical study was conducted over a three-month period with the aim of evaluating the TUI application, Tangible Cup in relations to its impact on older people's technology acceptance, social interactions, and quality of life.

6.1 Methods

The mixed of qualitative and quantitative approach can result in capturing more comprehensive outcomes of a study (Creswell, 2014; Wisdom, Cavaleri, Onwuegbuzie, & Green, 2012), which is suitable for this empirical study as the focus is on the impact of using the TUI application on older people's technology acceptance, social interactions, and quality of life. According to Wisdom et al. (2012), a study that aims to combine the strengths of both qualitative and quantitative designs, can provide more insight and comprehensive results. However, there are still some potential threats to validity with such methods. For instance, when using the convergent parallel approach, the use of different concepts or variables in both the qualitative and quantitative methods can result in incomparability and difficulty merging the findings (Creswell, 2014, p. 223).

Semi-structured interviews were conducted to collect qualitative data. The qualitative data focused on the experiences of older participants with using the TUI intervention and its impact on their technology acceptance, social interactions, and quality of life. The qualitative approach focuses on exploring the participants' communication, expectation, meaning, attitude, processes, and most importantly, interaction and relationships. These are described as the core components of clinical knowledge by K. Malterud (2001).

The semi-structured interviews are discussed in detail in Section 2.4.3 of Article III and the 'Interview' section of Article IV. A semi-structured interview guide (see Appendix III) was used while conducting the interviews, and follow-up questions were asked to clarify their answers. The aim was to gain deeper insight into their experiences with using the Tangible Cup and explore its potential.

The TAM questionnaire (see Appendix IV) and the OPQOL questionnaire (see Appendix V) were used to collect quantitative data. Both questionnaires are presented in detail in Section 2.4 of Article III.

The quantitative data aimed to capture older participants' technology acceptance and quality of life and the changes in them after using the TUI application statistically. Additionally, the statistical results could be used to validate the interpretation of qualitative data (Kelle, 2006).

6.2 Recruitment procedure and participants

From a previous project related to the quality of life, nutritional status, physical and pain, mental and social function of senior center users, potential participants were identified. The inclusion criteria for the empirical study were living alone, being older than age 70, and being able to walk independently with or without an assistive device indoors. The potential participants were contacted via telephone to brief them about this three-month study. Initially, we only included people who lived alone, but due to the difficulty of recruiting male participants who lived alone, we included one man who was still living with his wife (P14).

During our first visit to the participants, they were observed on how they used their smartphone, tablet, or both. Their ICT skill level was assessed based on these observations. A 'basic' ICT skill level indicates that they use a smartphone or tablet with some difficulty, while 'advanced' means they use a smartphone or tablet with minor problems, and 'very advanced' implies that they use smartphone or tablet without any problems. A summary of the participants' characteristics is depicted in Table 5.

Table 5. Summary of the participants' characteristics in the empirical study

	Age	Gender	Education (years)	Relationship status	ICT skills
P1	79	Female	12	Widow	Basic
P2	74	Female	11	Widow	Basic
P3	82	Female	21	Widow	Basic
P4	77	Female	10	Widow	Basic
P5	76	Female	14	Widow	Very advanced
P6	81	Female	15	Widow	Basic

P7	82	Female	10	Widow	Advanced
P8	72	Female	12	Widow	Advanced
P9	82	Female	13	Widow	Basic
P10	81	Female	14	In a relationship	Basic
P11	81	Female	19	Widow	Advanced
P12	89	Male	17	Widow	Advanced
P13	77	Female	11	Widow	Advanced
P14	83	Male	14	Married	Advanced
P15	83	Female	12	Widow	Advanced
P16	79	Female	12	Widow	Advanced
P17	77	Female	11	Widow	Advanced
P18	81	Female	8	Widow	Basic
P19	76	Female	13	Widow	Very advanced
P20	79	Female	10	Widow	Basic

6.3 Data collection

We visited the participants three times for data collection: pre-testing, mid-testing, and post-testing. During the first visit to the participants' homes, the Tangible Cup was demonstrated prior to them agreeing to participate in our study. The participants were instructed to use the Tangible Cup whenever they wanted. After one and a half months, we conducted the mid-testing visit. Post-testing was one and a half months after the mid-testing visit. Some participants requested more visits as they were having difficulty using the TUI application.

The OPQOL questionnaire was administered three times: during pre-testing, mid-testing (after one and a half month), and post-testing (after three months), while the TAM questionnaire was administered twice: during pre-testing and post-testing. After answering the questionnaire, semi-structured interviews were conducted to gain more insights and clarify their answers. Figure 16 visualizes the empirical study's research process.

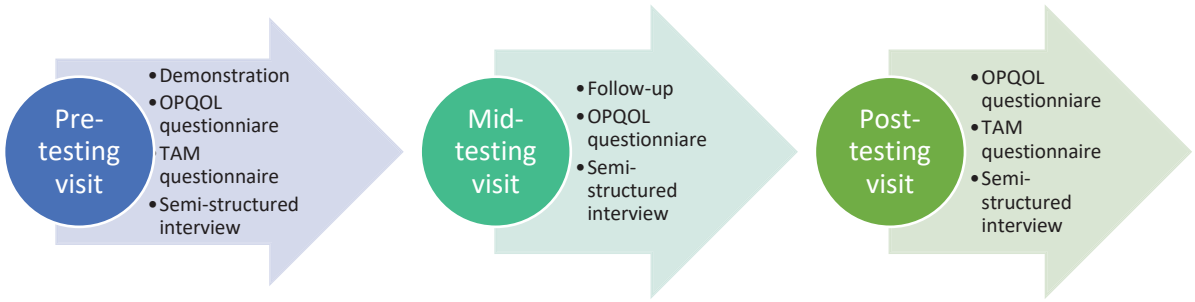

Figure 16. Data collection in the empirical study.

The two quantitative outcome measures in this study are OPQOL and technology acceptance. The OPQOL questionnaire was used to measure quality of life since it is a more sensitive instrument to measure the quality of life among older people in Britain than other quality of life questionnaires for older people, CASP-19 and WHOQOL (Bowling & Stenner, 2011). In terms of meeting the reliability criterion for item-total scale correlations, the OPQOL questionnaire scored better in the correlation tests for validity in the Ethnibus sample.

Using the TAM, factors that could possibly affect the participants' acceptance and use of the Tangible Cup could be identified. The TAM questionnaire was developed based on prior studies that used the TAM questionnaire to investigate older people's technology acceptance (Chiu et al., 2016; Dogruel et al., 2015; Hsiao & Tang, 2015; Lekjaroen et al., 2016; Mostaghel & Oghazi, 2017). These two instruments are described in detail in Sections 2.4.1 and 2.4.2 of Article III.

The main outcome measures for the qualitative data are the participants' experience in using the Tangible Cup, with the focus on the impacts on their social interactions and quality of life. A semi-structured interview guide (see Appendix III) was used to collect the qualitative data.

6.4 Data analysis

Changes in technology acceptance and OPQOL were described using median values. To analyze the associations between technology acceptance and OPQOL, Spearman's correlation

coefficients were computed. Significance at the 0.01 and 0.05 level (2-tailed) being considered statistically significant. The strength of correlations was interpreted according to Cohen's classification, where 0.10–0.29 is weak, 0.3–0.49 is moderate, and 0.5–1.0 is strong (P. Cohen, West, & Aiken, 2014). The associations for pre-testing were first computed using baseline scores. Then, the associations for post-testing were computed using changes from the baseline. This helps in clarifying that the associations were due to the use of TUI application. Details of the quantitative data analysis are presented in Section 2.6 of Article III.

For qualitative data analysis, two different methods were used: inductive content analysis and hermeneutic interpretation. The interviews were transcribed, and for inductive content analysis, the transcript was read and analyzed in three main steps, including open coding, creating categories, and abstraction (Elo & Kyngäs, 2008). For hermeneutic text interpretation analysis, each transcript was read and analyzed in five reads (Lindwall, von Post, & Eriksson, 2010). NViVo version 12 software was used to perform both the three-step inductive content analysis process and hermeneutic text interpretation analysis. Table 6 summarizes the processes for both analyses. Additional details of the inductive content analysis and hermeneutic interpretation approach are provided in Section 2.6 of Article III and the 'Data Analysis' section of Article IV,.

Table 6. A summary of qualitative data analysis in the empirical study

	Inductive content analysis	Hermeneutic interpretation approach
Step 1	Open coding: Notes and headings were written down while reading the transcript.	Integrated the text with the reader and 'Let the text itself speaks'
Step 2	Creating categories: The notes were grouped into categories to increase the understanding of the participants' use of Tangible Cup.	Interpreted and raised more questions.
Step 3	Abstraction: Formulated the generated categories from the previous step into a main category.	Understood the text and answered questions that could lead to another element of understanding.

Step 4	-	Summarized primary, secondary, and basic themes.
Step 5	-	Read the text again to compare all the themes from the previous reading to the text as a whole, so a new understanding could be formed.

6.5 Ethical considerations

This study involved processing personal data, such as sound recordings of the participants, background information that might identify the person, and etc. Prior to conducting the study, pre-approval and registration with NSD were obtained (reference number 253545; see Appendix VI). All data are stored and were processed on a physically isolated storage device belonging to the data controller/project leader (i.e. the Ph.D. candidate responsible for the project). The data storage is not connected to any network. Only the project leader, two internal supervisors, and a transcriber have access to the data. No data are shared with other institutions.

For this empirical study, informed consent was required prior to participating the study (see Appendix VII for the consent form). The participants were briefed with written and oral information about the study. They were assured of the confidentiality of their responses, and they were reminded that their participation was voluntary. We emphasized that they could withdraw from the study at any time without any adverse consequences. Once they understood and agreed to participate, they were asked to sign the consent form.

6.6 Results

The results from the empirical study are presented chronologically, from the recruitment process to post-testing (i.e., after using the TUI application).

6.6.1 The recruitment process

To recruit 20 participants for the empirical study, a total of more than 150 older people from a project related to quality of life, nutritional status, physical and pain, mental and social

functioning of senior center users were contacted via telephone. They were briefed over the phone about the project, and only 27 older people were interested. They stated that we could visit them and demonstrate the application.

Seven older people declined to participate in the study after we briefed them about the project and demonstrated the Tangible Cup. From our observations during these visits, most of them might have disliked being labelled 'lonely older people' in need of ICT to improve their social interactions. Some of them were concerned, thinking they were contacted because we observed that they had a low quality of life and low ICT use. Although we attempted to explain that the study was not solely focusing on older people who are lonely, they insisted that they had a good life, were socially active, and were busy. However, from our observation and conversation with these people, we suspect they were defensive. We noticed that these people might actually feel lonely. They were happy with our visit but reluctant to participate in the study. Some of them still kept their home telephone even though it was not used very much. They had smartphones but did not use them for functionalities other than sending SMS text messages and making phone calls. They appeared skeptical of using ICT.

Three participants contacted us and stated the Tangible Cup was not suitable for them after they had used it for a day. They withdrew from the study, and we recruited three new participants to replace them. The empirical study proceeded with 20 participants.

6.6.2 Withdrawal

After the first four weeks, four participants (P17, P18, P19, and P20) withdrew from the study. Their withdrawal is described in detail in the 'Reasons not to Use' section of Article IV.

6.6.3 The association between OPQOL scores and technology acceptance before using the Tangible Cup

No statistically significant correlation was found between OPQOL scores and technology acceptance before the TUI intervention.

6.6.4 Changes in technology acceptance after using the Tangible Cup

After the TUI intervention, 12 out of 16 participants improved their technology acceptance while the sum score of the TAM decreased for P9, P13, P14, and P16. Table 7 summarizes the TAM median scores by dimensions for the whole study.

Table 7. Summary of TAM medians by dimensions (D1–D8) for pre- and post-testing

Variables	Pre-testing median (range)	Post-testing median (range)
D1. Perceived usefulness	14.00 (3 to 19)	14.00 (3 to 19)
D2. Perceived ease of use	17.50 (7 to 25)	18.00 (12 to 23)
D3. Perceived enjoyment	20.00 (10 to 28)	20.50 (14 to 28)
D4. Intention to use	6.00 (4 to 7)	6.00 (3 to 7)
D5. Actual use	6.00 (3 to 7)	6.00 (4 to 7)
D6. Compatibility	12.50 (3 to 21)	15.50 (7 to 21)
D7. Attitude	10.50 (7 to 14)	12.00 (9 to 14)
D8. Self-efficacy	17.00 (11 to 21)	17.00 (14 to 21)

Among the median scores of all 8 dimensions of the TAM, D6 (compatibility) increased the most, followed by D7 (attitude), D2 (perceived ease of use), and D3 (perceived enjoyment). D1 (perceived usefulness), D4 (intention of use), D5 (actual use), and D8 (self-efficacy) remained unchanged. These results are depicted in Figure 3 of Article III. Table 4 of Article III summarizes the TAM scores by scale and dimension in percentages. The details are described in Section 3.2 of Article III.

6.6.5 Changes in OPQOL scores after using the Tangible Cup

Table 8 summarizes the median OPQOL scores by dimension and Q (overall quality of life) for the entire testing. The median score of Q (overall quality of life), D1 (life overall), D4 (independence, control over life, freedom), D5 (home and neighbourhood) and D7 (financial circumstances) did not change when pre-testing was compared with post-testing. D2 (health)

and D6 (psychological and emotion well-being) scored higher at the post-testing while D8 (leisure and activities) scored lower. D3 (social relationships and participation) is the only dimension showing a negative correlation over time. These results are depicted in Figure 4 of Article III.

Table 8. Summary of OPQOL medians by dimension (D1-D8) and Q for pre, mid- and post-testing

Variables	Pre-testing median (range)	Mid-testing median (range)	Post-testing median (range)
D1. Life overall	16.00 (13 to 20)	17.00 (12 to 20)	16.00 (13 to 20)
D2. Health	14.00 (10 to 20)	15.00 (10 to 20)	15.00 (9 to 20)
D3. Social relationships and participation	19.50 (13 to 23)	19.00 (14 to 24)	18.50 (12 to 23)
D4. Independence, control over life, freedom	16.00 (14 to 20)	17.00 (14 to 20)	16.00 (13 to 20)
D5. Home and neighborhood	17.00 (14 to 20)	17.00 (14 to 20)	17.00 (14 to 20)
D6. Psychological and emotion well-being	16.00 (14 to 20)	16.50 (13 to 19)	16.50 (13 to 20)
D7. Finance circumstances	16.00 (11 to 20)	15.50 (9 to 20)	16.00 (11 to 20)
D8. Leisure and activities	22.00 (14 to 28)	24.00 (14 to 28)	21.50 (17 to 27)
Q. Statement evaluating overall quality of life	4.00 (2 to 5)	4.50 (3 to 5)	4.00 (3 to 5)

Out of all the variables (D1-D8 and Q), D8 (leisure and activities) changed most significantly (i.e. a change of more than 1 point, from 22.00 to 24.00 and from 24.00 to 21.59). Although the results for all the variables are presented, using the Tangible Cup is believed not to have any relationship with D7 (financial circumstances).

It is worth mentioning that when we examined individual scores, more participants had greater changes (i.e., score changes of more than 4 points) in D3 (social relationships and participation) and D8 (leisure and activities) than any other dimension. This indicates that using the Tangible Cup had an impact on these two dimensions, and they probably most closely related to social interaction. From mid-testing to post-testing, three participants' scores on D3 (social relationships and participation) had changes more than 4 points: -8 points for P1, +6 points for P5, and -5 for P14. On D8 (leisure and activities), P9's and P11's scores dropped 5 points from mid-testing to post-testing.

Talking to new people and having more social interactions are related to D3 (social relationships and participation), and the participants' intention to join this study is related to D8 (leisure and activities). Most of the participants were interested in helping others who need to talk to someone. When we examined the individual scores for individual questions in D8 (leisure and activities), question 31 and 32 ('I try to stay involved with things' and 'I do paid and unpaid work or activities that give me a role in life') have a similar pattern. In these two questions, most participants' scores increased by the mid-testing and then declined in the post-testing.

This pattern was observed in question 10 of D3 (social relationships and participation; i.e., 'I would like more companionship or contact with other people'). Using the Tangible Cup was more exciting at the beginning of the study for most participants. They used TUI application more frequently, and their scores on question 10 (D3 - social relationships and participation) and questions 31 and 32 (D8 - leisure and activities) increased at the mid-testing.

6.6.6 Association between changes in OPQOL scores and technology acceptance after using the Tangible Cup

The Spearman's rank-order correlation results indicate some relevant statistically significant correlations. First, D5 of the OPQOL (home and neighbourhood) has a significant positive correlation with overall technology acceptance (TAM), D2 (perceived ease of use), and D8 (self-efficacy). Second, Q of the OPQOL (first question assessing overall quality of life) is negatively correlated with D5 (actual use) and positively correlated with D7 (attitude) in TAM. Lastly, D4 in TAM (intention of use) is also positively correlated with the OPQOL (total score) and D7 in OPQOL (financial circumstances). However, use of the Tangible Cup

was not expected to have an on the participants' financial circumstances. Detailed information regarding Spearman's rank-order correlations are shown in Table 5 of Article III.

6.6.7 Changes in older people's social interactions and quality of life

The qualitative data shows that some participants enjoyed the conversations that they had, which means the Tangible Cup could have contributed to better social interactions. The quantitative data support this finding. P5's score on D3 (social relationships and participation) increased 6 points, which is also the most improved participant on D3 from mid-testing to post-testing. While using the Tangible Cup for more than six weeks, she talked to some users and found it enjoyable to talk to them. She is one of the participants who would consider meeting the other users in person.

However, some participants did not enjoy the conversations. One of the reasons was they do not like talking to strangers. This is further discussed in Section 7.5. Another reason is they do not like to open up (i.e., a reason not to use, presented in Article IV). However, they agreed to participate in the study because they wanted to help. They thought they could help other participants in the study who might needed someone to talk to, which resulted in the increase on D8 (leisure and activities) of their OPQOL.

The qualitative data analysis revealed reasons for the participants to use and not use the Tangible Cup. These reasons influenced changes in their social interactions and quality of life. Two main reasons to use are the participants experienced good conversations, and they were motivated by several factors, such as hoping for more calls, seeing the TUI object as an interesting way to use ICT and the potential for dating. However, difficulty in making contact, the unsuitability of the Tangible Cup for their personality and social life, and their experiences of bad conversations contributed to reasons not to use. Four participants withdrew from the study for some of these reasons.

A mismatch was also identified between the participants' attitudes and behaviour in relation to using the Tangible Cup and its design. The participants tended to forget things easily, and the Tangible Cup did not have a design and features that could compensate for this problem. This resulted in the failure to log out properly. Moreover, usability issues, such as no ring tone on the caller's side when making calls and the absence of a missed call indicator, were also identified. All these findings (reasons to use and not to use, and the mismatch) are presented in detail in the 'Results' section of Article IV.

7 Discussions

In the following sections, the Ph.D. research is reflected on and discussed in relation to several aspects: the TUI design (Section 7.1); methods used to design and develop the Tangible Cup and the validity and reliability of the research methods (Section 7.2); older people as the target user group for this research (Section 7.3); the relationship between technology acceptance, social interactions, and quality of life (Section 7.4); one of the main features of the Tangible Cup, calling and talking to strangers (Section 7.5); the strengths and limitations of the research (Section 7.6); and future work (Section 7.7).

7.1 TUI design

Through the research, several TUI designs that can accommodate the special needs of older people were identified. One of the most important design principles is integrating TUI into older people's daily lives (Bong & Chen, 2019). The integration of new tangible objects in one's environment was identified as a challenge (Wallbaum, Matviienko, Heuten, & Boll, 2017). To address this, the ways the TUI object was to be used daily by older people were kept in mind. The Tangible Cup was originally coupled with a table mat. However, in reality, older people do not use their cup in just one place, and the table mat was too large to carry around. The design of the Tangible Cup therefore changed to having cup coasters and a cup attachment. Fox (2018) highlighted the importance of integrating TUI applications into older people's daily lives when developing a TUI application (i.e., Nettle). The aim of Nettle is to integrate casual social interaction into one's daily routine. The design of Nettle is based on a tea set. Therefore, if the user can make tea, the user knows how to use Nettle.

TUI designs that target for older people should provide necessary instructions (Bong & Chen, 2019) and automated functions. Instructions could help in error prevention and recovery (Nielsen, 1995), while automation has been demonstrated to be able to assist older adults in tele-homecare (Nourizadeh, Deroussent, Song, & Thomesse, 2009). Some older people might suffer from age-related memory decline and become more forgetful (Craik, 1994). The participants in the empirical study encountered several usability challenges when using the Tangible Cup, such as accidentally turning down or switching off the volume and forgetting to log out properly. Necessary instructions and automated functions could help address these usability challenges. For example, alert messages can be prompted on the tablet when the user

accidentally turns down or switches off the volume (i.e., providing necessary instruction), and users can be logged out automatically after a long period of inactivity (automated function).

Spreicer (2019) suggested several TUI designs that can contribute to providing more accessible communication technologies for older people, and the findings of this research support some of them. The TUI designs include TUI objects having the right material and shape to achieve perceived affordances for the interface element, the TUI application having a small number of necessary interaction steps to increase the perceived ease of use, and being easy to learn. Throughout our focus group interviews and implementation iterations, we found older people's physical ability needs to be considered (Section 5.4.3). The results from the empirical study supplement the TUI designs in terms of having a small number of necessary interaction steps to increase the perceived ease of use and being easy to learn. The participants appreciated that the interaction steps were simple, and they only needed to use five cup coasters to perform all the necessary interactions. Therefore, they felt that the Tangible Cup was easy to use and learn.

Older people are a very diverse user group when it comes to the use of ICT (Bong & Chen, 2015, 2019; Y.-R. R. Chen & Schulz, 2016; Hallewell Haslwanter et al., 2018). Due to this diversity, some participants in the empirical study enjoyed their conversations, while others did not. The Tangible Cup was not suitable for all the participants, especially when their ICT skills were already good, and they were already busy with their existing social life. In addition, a mismatch was observed between the attitudes and behavior of older participants in using ICT and the design of the technology itself. For instance, they tended to forget things easily, and the design of Tangible Cup lacks reminding and suggestive features. We reflected upon these findings and the characteristics of a target user group for whom a TUI is suitable were identified. These characteristics are discussed further in Section 7.3.

7.2 Methodology aspect

7.2.1 User-centered design and co-design approach

User-centered design (Ehrenstrasser & Spreicer, 2013; Foverskov & Binder, 2011; Kern et al., 2006; Spreicer et al., 2012; Tellioğlu et al., 2012; West et al., 2007) and the co-design approach (Göllner et al., 2010; Raviselvam et al., 2014; Steen et al., 2011) were used in the focus group interviews and iterations with design, implementation, and usability testing. These methodologies guided the design of the Tangible Cup from discussions and

brainstorming on sketches to the end product. The user involvement started as early as we could, prove to be essential. This supports the finding by Hallewell Haslwanter et al. (2018), as mentioned by them that 'the development teams do not always understand the real needs.' In addition, working iteratively and allowing older people to provide feedback at early stages can help in detecting problems early.

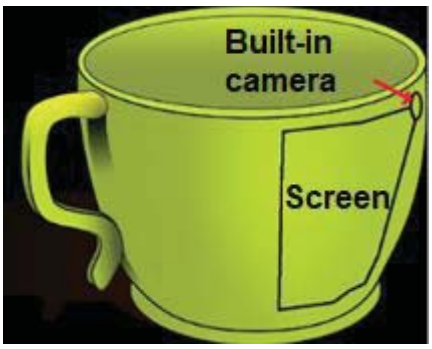

Figure 17. Original proposed design of the Tangible Cup.

The original idea of the Tangible Cup (see Figure 17) was to have all functions and features integrated into the cup itself. However, during the focus group interview, the participants informed us that most older people they knew tend to struggle with small buttons and 'confined' user interfaces for interaction. As a result, they coupled the Tangible Cup with a saucer installed with buttons (see Figure 8) to eliminate having all the buttons built into the cup itself. The design of the Tangible Cup was, thus, being extended from just a cup to a cup coupled with a table mat (see Figure 9). Through the iterations of implementation, the design changed from having the tablet mat (see Figure 9) to having cup coasters and a cup attachment (see Figure 10).

7.2.2 Validity and reliability

According to Bowling (2014, pp. 179-182), there are many threats to validity and reliability in research. She defined validity as the rigour of a study, with bias minimized, enhancing results and estimates, while reliability as the extent to which the measure is consistent and minimizes random error (i.e., its repeatability). Internal validity refers to the extent to which the instrument measures what it purports to measure, and external validity is the extent to which the research findings can be generalized to wider population of interest and applied to different settings. These concepts were considered while designing the Ph.D. research so that

the threats can be minimized, and both the validity and reliability of the study could be increased.

Creswell (2014, pp. 174-176) divided threats to validity into two types: internal validity threats (e.g., history, maturation, regression, selection, mortality, diffusion of treatment, compensatory/resentful demoralization, compensatory rivalry, testing, and instrumentation) and external validity threats (e.g., the interaction of selection and treatment, interaction of setting and treatment, and interaction of history and treatment). The empirical study faced various threats, such as interview bias, recall (memory) bias, and mood bias. These are internal validity threats as they possess bias that prohibits the instrument from measuring what it purports to measure.

The choice of outcome measures can impact both the internal and external validity of the research. The overarching research goal was to explore the ways TUI impacts home-dwelling older people's technology acceptance and quality of life by enhancing their social interactions. Therefore, the identified outcome measures included technology acceptance, social interactions, and quality of life. The use of a mixed qualitative and quantitative methodology approach in the empirical study contributed to more valid and reliable data collection and analysis. A more comprehensive outcome of the Ph.D. project was captured using this approach (Creswell, 2014; Wisdom et al., 2012).

While analyzing the qualitative data, concepts such as credibility, dependability, confirmability, and transferability (Lincoln & Guba, 1985) were discussed. It is important to ensure that qualitative data collected are valid and reliable, in which researchers have to be careful with transferability by not misinterpreting the meaning of the respondent, as suggested by Kirsti Malterud (2016). The use of quantitative data was helpful when it could provide statistical results (TAM scores and OPQOL scores) to validate our interpretation of qualitative data: older people's technology acceptance, social interactions, and quality of life (Kelle, 2006).

To achieve credibility, semi-structured interviews were conducted with open-ended questioning from the very first focus group interview to the post-testing in the empirical study. This concept is important, as we were aiming to explore a big research area, the ways TUI can impact home-dwelling older people's technology acceptance and quality of life by enhancing their social interactions. During data analysis, transferability was then achieved by

providing an in-depth, detailed, and descriptive analysis of the data and by quoting participants' responses to substantiate the findings. This is demonstrated specifically in Article IV, which focuses solely on data analysis using the hermeneutic interpretation approach. In addition, the transcriptions were reviewed several times using both inductive content analysis and the hermeneutic interpretation approach. The results from both analyses were compared and checked. Initial coding was performed by the principal researcher, and theme-formulation was then discussed and validated after discussions with all the co-authors to achieve dependability. Additional interpretations were arrived at based on consensus among all the authors. We attempted to obtain confirmability by substantiating each emergent theme with rich quotes extracted from the participants' responses.

Since semi-structured interviews were conducted, interviewer bias and observer bias might have occurred. This is due to the interviewers, who are the researchers themselves, already have their own understanding of the field. Thus, they might lead interviewees to the answers they are 'interested in;' because they collect the data, they are the first person to 'interact' with it (Bowling, 2014, p. 179; Pannucci & Wilkins, 2010; Patton, 2005, p. 4). To avoid interview bias, the interviewer's interactions with interviewees were standardized (Pannucci & Wilkins, 2010) using the semi-structured interview guide. Furthermore, the semi-structured interview was mostly conducted by a research assistant who had a more neutral position in this study.

In terms of recall (memory) bias and mood bias, the way the respondents recall their past experiences and their feelings can bias their answers, especially when they were answering the OPQOL and TAM questionnaires. We had conducted a validation study to validate the OPQOL questionnaire, and one of the findings was that some of the participants reportedly felt their feelings could influence their answers. Van den Brink, Bandell-Hoekstra, and Abu-Saad (2001) studied the occurrence of recall bias in pediatric headaches and found that headache intensity and duration were overestimated on a questionnaire when compared to a diary.

According to Ellenberg (1994), selection bias is an error influencing internal validity when the study population does not represent the target population. In this research, we acknowledge one of the important factors affecting selection bias, the criteria for including and excluding participants in the research study. In this research, the inclusion criteria were that they lived alone, were over 70 years, and were able to walk independently with or

without an assistive device indoors. These criteria were not specific enough to reach the target user group for our TUI application. In the next section, the target user group is described in detail.

7.3 Older people as the target user group

Older people or elderly people are defined as the population age 65 and above (WHO, 2002). Originally, the target user group for this research was home-dwelling older people living alone who might be at risk for socially isolation and loneliness. The entire research project, from the systematic literature review studying the state-of-the-art in TUI for older people's social interactions to having 20 older participants use and test the Tangible Cup for a period of three months, has demonstrated and supplemented an important finding (i.e., older people are very diverse as a user group). As mentioned in many studies related to older people using ICT, the diversity of older users should be considered when designing ICT for them (Bong & Chen, 2015, 2019; Dickinson & Gregor, 2006; Hallewell Haslwanter et al., 2018).

Y.-R. R. Chen and Schulz (2016) concluded in their review of the effect of ICT interventions on reducing older people's social isolation that, ICT is not a one-solution-fits-all with respect to older people. Supporting this conclusion, almost all of the participants from the three-month longitudinal study were not the right target user group for using the TUI application developed and tested in this study. The inclusion criteria in the longitudinal study were that they lived alone, were over 70 years of age, and were able to walk independently with or without an assistive device indoors. The longitudinal study revealed more characteristics of the target user group that can benefit the most from using a TUI application. These characteristics are illustrated in Figure 18.

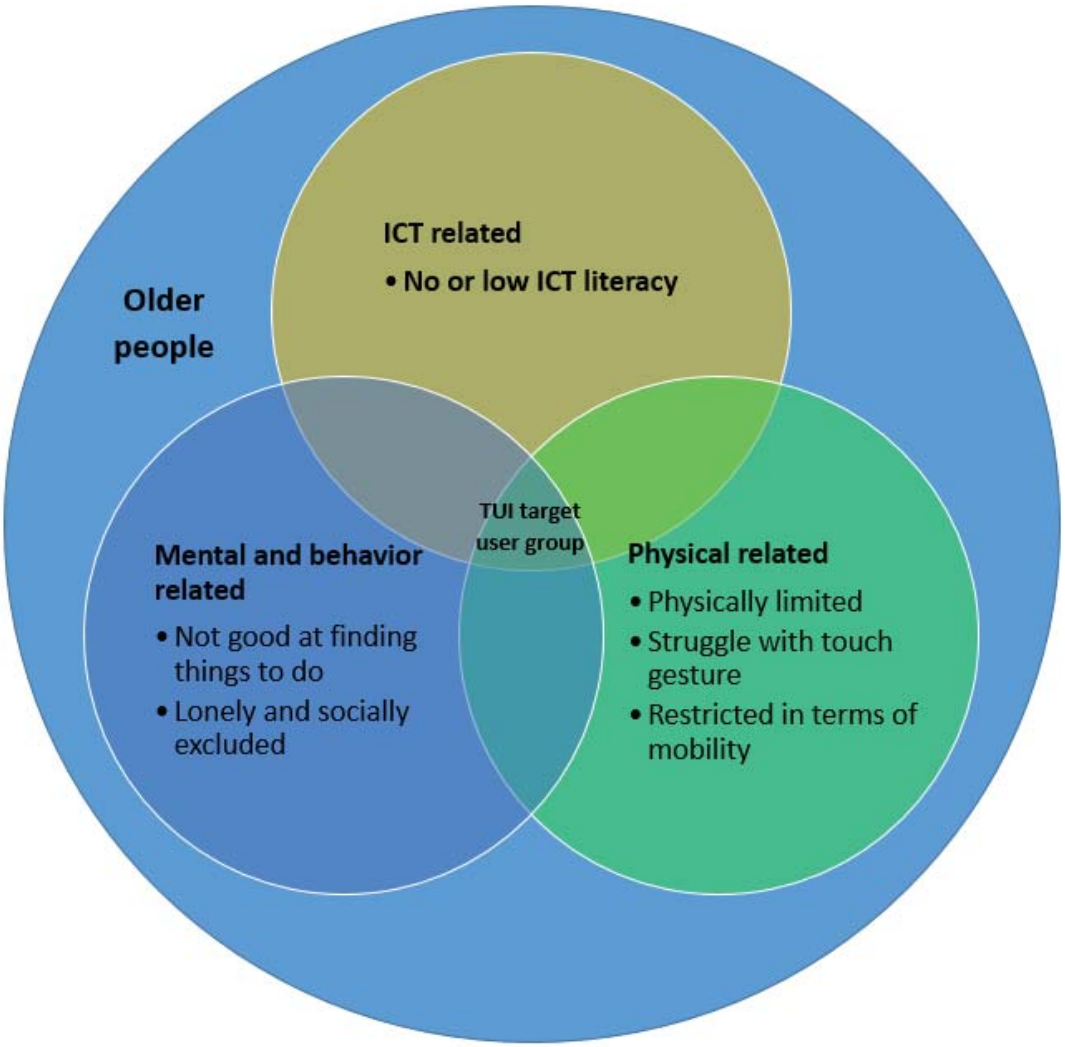

Figure 18. The identified target user group of Tangible Cup after the longitudinal study.

As older people age, some of them might suffer from physical limitations, such as walking difficulty, weak muscle control, or mobility restriction due to slippery roads outside during the winter. TUI has been identified as suitable for this group of older people, especially for their social interactions (Angelini et al., 2016; Ehrenstrasser & Spreicer, 2013; Fox, 2018; Spreicer, 2011b; Wallbaum et al., 2018) and quality of life (Marques et al., 2011). Some older adults found the use of touch screen devices, such as tablets, challenging (Barnard et al., 2013; Vaportzis et al., 2017). Compared to laptops and personal computers, touch screen devices and the user interfaces in tablets were more difficult to understand (UISEL, 2015). Vaportzis et al. (2017) revealed in their empirical study that older adults found the buttons on a tablet cumbersome. Without labels and names, the participants made mistakes and confused the power button with the volume button.

The difficulties encountered in reaching older people who were lonely are worth mentioning. As mentioned in Section 6.6.1, during the recruitment process, it was witnessed that older people who were lonely and socially isolated did not like to be labelled as such. Yong, Bell, Workman, and Gibson (2003) discussed 'cautious-attitudes,' which refers to being reluctant to label something as painful, avoiding labeling something as painful, and lacking confidence in labeling something as painful. These participants, who were reluctant to participate in our study, were believed to have cautious attitudes, as they did not want to be seen as having or feeling 'pain,' being socially isolated, or feeling lonely and needing help.

The participants in the empirical study were not lonely older people. They visited senior centres regularly and that was one of the signs that they found things to do by themselves. Most of the participants provided the reason they were interested in participating the longitudinal study, and it was to help other older people in need of someone to talk to; hence, they wanted to help rather than be helped. In a report on volunteering by older people in the European Union, Ehlers, Naegele, and Reichert (2011) stated that voluntary involvement by older people can minimize their risk of being socially isolated. It can also promote 'active aging,' where older people can remain healthy, productive, and involved in their communities.

Moreover, all the participants in the empirical study had average or advanced ICT skills. Spreicer (2019) proposed the elements of an TUI that can support older ICT users in their interactions with ICT. They included playful design and high learnability, reduced interaction steps, and personalized visual annotation. The findings of the empirical study may suggest that these elements can benefit older people who are not average or advanced ICT users. Having no or low ICT skills is one of the characteristics of the target user group we have identified, and the above-presented elements make TUI more suitable for this user group than others.

7.4 The relationship between technology acceptance, social interactions, and quality of life

According to P. Cohen et al. (2014), a correlation is weak when the correlation coefficient is 0.10–0.29, moderate when it is 0.3–0.49, and strong when it is 0.5–1.0. The findings from the empirical study indicate that when older participants had a more positive attitude toward the Tangible Cup (D7 – attitude in TAM), their overall quality of life (Q - first question accessing

overall quality of life in OPQOL) increased (correlation coefficient = 0.69). This correlation is strong. When the associations between dimensions in the TAM were analyzed by computing Spearman's correlation coefficients, perceived enjoyment (D3 in TAM) was found to have a positive correlation with attitude (D7 in TAM), and this correlation coefficient is 0.50. Older people may have a more positive attitude toward using ICT or, specifically, the Tangible Cup, when they find it fun and enjoyable to use or vice versa. This finding is consistent with previous studies suggesting that enjoyable experiences contribute to positive attitudes (Davis et al., 1992; Huang, Lin, & Chuang, 2007; Praveena & Thomas, 2014).

However, the correlation coefficient for perceived enjoyment (D3 in TAM) and overall quality of life (Q in OPQOL) was only 0.42. The qualitative finding might be able to explain why this correlation is only a 'strong moderate.' Only around half of the participants found their conversations and social interactions using the Tangible Cup enjoyable. This finding was reflected upon the personality and lifestyle of the participants. Not all of them were willing to open up when they had conversations. Their more reserved personality restricted the topics of conversation they could talk about when using the Tangible Cup. This is related to their diversity, and this diversity is not about their use of ICT, but their personality, which differs from person to person regardless of age (Asendorpf & Wilpers, 1998; McCrae, 1996). The topic of calling and talking to strangers is discussed in further detail in the next section. In addition, when older participants already had a busy social life, they did not seem to have the need to improve their social life and social interaction.

It is worth mentioning that the qualitative data contributed to most of the findings regarding older participants' social interactions. The participants' technology acceptance and quality of life were analyzed and interpreted using both the qualitative and quantitative data. The findings suggest strongly that there are relationships between these three aspects. As illustrated in the conceptual framework (see Figure 4), social interaction plays a role in older people's quality of life. This has been proven in prior studies (Corner et al., 2006; Gilmour, 2012; Huxhold, Miche, & Schüz, 2013; Thomas, 2009). After attempting to use a TUI application to impact older people's social interactions, our findings indicate that their social interactions were impacted in both positive and negative ways. As discussed in previously, the positive impacts are strongly related to the participants' personality, which is also reflected in 'reasons to use' in Article IV. Additionally, the design of the Tangible Cup impacted their social interactions, mostly in negative ways. These are reflected in 'reasons not to use' and the mismatch between the ways older people use ICT and the design of the ICT in Article IV.

When relating the social interactions between older participants using the Tangible Cup and their quality of life, it can be concluded that the social interactions were not enough to have a significant impact in the participants' quality of life, especially when the empirical study was only a pilot study and usability issues remained. Nevertheless, impacts on D3 (social relationships and participation) and D8 (leisure and activities) in the OPQOL were observed. The three-month empirical study period might be too short to reflect on the results of the TUI intervention in relations to quality of life.

7.5 Calling and talking to strangers

Calling and talking to strangers is an important feature of the Tangible Cup. It influenced the ways participants used the Tangible Cup and, therefore, their social interactions. This feature was perceived very differently among the participants. Some of them commented that the Tangible Cup concept is interesting but not the feature of calling strangers. Other participants felt that talking to strangers was normal for them, and a few of them reflected on their previous jobs where they had to talk to strangers routinely. This difference in behavior was examined by Peters, Kashima, and Clark (2009), who concluded that the communicability of emotional social talk varied with the audiences' identity (i.e. whether they are known or unknown), which could be associated with the person's personality (Asendorpf & Wilpers, 1998; Fishbein & Ajzen, 1980; Luszczynska & Schwarzer, 2005; McCrae, 1996; Wood & Bandura, 1989). Some people are more open than others. This can certainly effect their use of the Tangible Cup, which impacts their social interaction, technology acceptance, and quality of life as a whole.

One surprising finding was that a few of the participants used the Tangible Cup as a dating platform. Alterovitz and Mendelsohn (2011) studied older people's online dating and found that women were more selective than men when dating at that age, which is consistent with our findings. P18 was the only man in the Tangible Cup group he participated in, and he was open for any possibility to talk to any woman in the group. The women in that group, however, were more skeptical. Most of the women participants even voiced a fear of making the first move to call the only guy (P18) in the Tangible Cup group. Dating was seen as more common for older men than women, according to Brown and Shinohara (2013).

7.6 Strengths and limitations

This Ph.D. research could contribute new knowledge to society, computer science, the social sciences, and health science. The TUI concept was introduced by Ishii and Ullmer (1997) more than 20 years ago, but the systematic literature review revealed that TUI has not been widely used (Bong et al., 2018). The systematic literature review resulted in only 21 papers, with three of them focused on the same prototype. This clearly shows that very little research has been conducted on the topic of TUI for older people's social interactions. Even though these papers had the objective of designing, developing, and evaluating a prototype that should address issues faced by older people in terms of their social interactions, most of them only focused on the usability aspect of the prototype. Social interactions of older people were neglected in most studies, especially when evaluating the TUI application and the effects of using it.

The backgrounds of the researchers involved in this research (i.e., human-computer interaction and health sciences) is reflected in the study design, data collection, analysis and interpretation. A strength of the mixed background is that the research decisions were reflected upon 'rationalization' and 'reasonable.' These two behaviors have been discussed by Sayer (2011, pp. 59-97). He argues the importance of these two behaviors; when improvements that make life easier take place, problems that accompany these improvements have to be resolved With the emergence of ICT to enhance our lives, we have to ensure that older people, as a user group, are taken care as well so that the goal of implementing these ICTs is achieved. This is demonstrated by achieving the overarching Ph.D. research goal.

The empirical study adopted an interdisciplinary approach, one of the knowledge gaps identified in the systematic literature review. The focus of the empirical study was on the usability aspect of the application and the technology acceptance of the participants, as well as health related outcome measures (i.e., social interactions and quality of life). The TUI application was designed to address the real needs of older people in relation to their technology acceptance, social interactions, and quality of life. The study involved researchers from an interdisciplinary background, and by doing so, it is hoped that rationalization and reasonable behaviors were achieved.

Using the OPQOL questionnaire in the empirical study has both strength and limitation. To the best of our knowledge, this was the first time a study has used the OPQOL questionnaire

in an ICT-related intervention. The OPQOL has only been used in health science-related studies previously (Bilotta et al., 2011; Kojima et al., 2016). In addition, no study has used the OPQOL questionnaire in the Norwegian context, so it had to be translated into Norwegian. Translation was done based on on the guidelines developed by Beaton, Bombardier, Guillemin, and Ferraz (2000). However, the Norwegian version of the OPQOL questionnaire was not validated before the data collection began. Validating the Norwegian OPQOL questionnaire is essential, as the translated OPQOL questionnaire should reflect the country's sociocultural traditions and background. The OPQOL questionnaire has been translated and used in other countries (Caliskan et al., 2019; Y. Chen, Hicks, & While, 2014; Mares, Cigler, & Vachkova, 2016). In the Czech version, Mares et al. (2016) reversed the five grade scale and adopted the more familiar Czech school grading system for older people living in the Czech Republic. In China, the Chinese interpreted 'leisure and social activities' as two separate dimensions ,while the original English version put them in one (Y. Chen et al., 2014). In Turkey, an explanatory sentence (i.e., 'There are things that will make me happy when they happen') was needed for the statement 'I look forward to things' to reduce the likelihood of the statement being misinterpreted as insatiability by individuals participating in the study (Caliskan et al., 2019).

A validation study was conducted along with the post-testing, and the data analysis will be completed soon. Using the three-step test-interview approach described by Hak, van der Veer, and Jansen (2004), this validation study was conducted with 14 participants from the longitudinal study, and the data collected were analyzed using the hermeneutic interpretation approach. The results are expected to provide an overview of the adjustments needed to reflect sociocultural differences among older people in Norway.

Other strengths and limitations of the study involve the design of the Tangible Cup. The Tangible Cup is an outcome of the innovation research process, where the idea was inspired by the Norwegian coffee drinking culture and developed further using a user-centered and co-design approach (Bong & Chen, 2019). The results shows that integrating TUI into the daily life of older Norwegians, particularly with regard to their coffee drinking culture, has the potential to enhance their technology acceptance, social interactions, and quality of life. However, it is worth mentioning that the design and development processes were only conducted for four iterations, along with one focus group interview. The limited amount of time and resources restricted the further development of Tangible Cup, and the consequences of this were captured in usability challenges encountered by the participants in the empirical

study. Therefore, suggestions to improve the Tangible Cup have been gathered and are presented as future work in the next section. Nevertheless, it is important to highlight that the Tangible Cup is the technical contribution of this Ph.D. research.

The participants are also the strengths and limitations of this study. As discussed in Articles III and IV, the participants were not representative of the older population in Norway. A sample is the representative of a given population when the sample chosen is drawn without bias, which means the people in the sample group are similar to the other members in the target population (Creswell, 2014, pp. 158-159; Guarte & Barrios, 2006). This limitation was due to problems encountered in the recruitment process.

Since we recruited the participants through their previous involvement in another study conducted at senior centers, their socio-demographical background was similar. All senior centers are located in Oslo, and they are residential-area based. All the participants in the longitudinal study were ethnic Norwegian. Hence, we acknowledge that there is a lack of well-represented diversity of socio-demographical backgrounds among the participants. According to SSB (2019a), there are 806,694 older people age 66 or older living in Norway. Out of this number, 41,933 (5% of the total population) are either immigrants or Norwegian-born with immigrant parents (SSB, 2019b); hence, they are not ethnic Norwegian, and the number is expected to reach 15% in the next 30 years according to Johannessen, Tretteteig, Molvik, and Langballe (2017).

However, the strength of studying this group of older people is that they can be seen as potential lead users. In a study conducted by Raviselvam et al. (2014), older people were tested to see if they could be lead users, providing ideas for product innovations that were also preferred by the general population. The results show that the needs and requirements of older users could be used to design universally acceptable products. The ICT skills of older participants in the longitudinal study were basic and above (see Table 5). They were able to use ICT on a daily basis. Their suggestions and feedback were seen as applicable not only to older people with lower ICT skills but also users in other age groups, including the younger generation. They suggested extending use of the Tangible Cup to friends and family members who are younger. Younger user groups and other older people who have basic and above ICT skills could use the calling application rather than the full Tangible Cup set.

In addition, older people living alone are not necessarily lonely (Smith & Victor, 2019). In the study exploring typologies based on shared experiences of loneliness, social isolation, and living alone, Smith and Victor (2019) identified six groups of older people among 82,49 who participated in their study based on the typologies; 9.03% were identified as both living alone and having moderate loneliness (referred to as Group 5 in the study), while 11.79% were living alone without having signs of moderate loneliness (Group 3). Although both groups were reportedly living alone, the group with signs of moderate loneliness (Group 5) reported sometimes experiencing feelings of lacking companionship at a rate of 73.1%, while it was only 29.1% in Group 3. Only 3.6% of Group 3 reportedly felt isolated sometimes, while 69.8% of Group 5 felt that way. We acknowledge that not all home-dwelling older people who live alone are lonely, and therefore, we did not reach the target group successfully.

Through the longitudinal study, the potential and target user group that the TUI is suitable for were identified. Among older people, those who have minimal or low ICT literacy or skills, might have physical limitations, struggle with touch gesture interfaces, are restricted in terms of mobility, are not good at finding things to do, and feel lonely and socially isolated are the target user group for which the TUI is best suited. Ways to reach this group of target users are discussed in the next section. By reaching this user group, it is hoped that they can benefit from the use of TUI. With improved technology acceptance, social interactions, and quality of life, they can be among the healthier aging population.

7.7 Future work

Throughout the entire Ph.D. research project, a list of future work was compiled. The first relates to the best way to approach the target user group for whom TUI is best suited. Career history, race, ethnicity, educational background, culture, and class are important factors that shape different characteristics of older users, which directly lead to, for example, differences in needs, goal setting, and life satisfaction (Erez, 2013; Gillborn, 2015). Older people in Norway with a higher socioeconomic status have better social networks, which protect them against loneliness, and thus, they have better health and quality of life (Rogne & Syse, 2017). Older people who are non-ethnic Norwegian should be reached out to in a future study. According to Moen, Danielsen, Haneset, and Nordahl (2015), this group of older people do not attend activities at elderly centers like ethnic Norwegian older people. Instead, they prefer to meet other older people at locations such as mosques and cafes; thus, they could be good places to recruit non-ethnic Norwegian participants.

Other type of users should be considered for the Tangible Cup, thus extending the target user group to include individuals who are not older, such as healthcare personnel and caretakers. Relationships between health professionals, such as therapists and patients (Hall, Ferreira, Maher, Latimer, & Ferreira, 2010; Hornos et al., 2018) and professionals in research and patients (de Wit et al., 2011), have proven to have a positive effect. Hornos et al. (2018) designed a web-based ICT system with which therapists can configure and supervise activities carried out by patients. Social isolation and loneliness should not be seen as a kind of sickness or disease, and older people who feel lonely but are not familiar enough with using ICT tools to stay socially connected are not 'patients.' However, many older people do experience sickness and diseases that require the services of healthcare personnel and caretakers. Hence, healthcare personnel and caretakers, as Tangible Cup users, can contribute to helping older people remain socially active.

Older people, as an ICT user group, often need extra guidance and help with their ICT use. This holds true for the empirical study's participants, as we observed in their use of the Tangible Cup. Additional tasks were required to set up the Tangible Cup for them, and they requested assistance whenever they encountered difficulty using it. In Spreicer (2019) work on *kommTUi*, additional tasks were also required, such as installing the Java service on the user's computer, configuring the Java service, and maintaining the hardware and the Java service. Therefore, he suggested involving relatives and caretakers who can set up IT devices and provide help when needed.

Another group of Tangible Cup users could be older people's friends and family members because they are important actors in the social lives of older people (Corner et al., 2006; Huxhold et al., 2013; Sabin, 1993; Seeman, 2000). According to Neves and Amaro (2012), one of the reasons older people use ICT is their friends and family members. Therefore, it is important that Tangible Cup users can be extended to include friends and family members. However, it is believed that friends and family members, as well as healthcare personnel and caretakers, might not need the TUI object as much as older people who have low ICT skills. Hence, this group of users could use the mobile application without the TUI object. As suggested by social cognitive theory (D. Compeau et al., 1999; Luszczynska & Schwarzer, 2005; Wood & Bandura, 1989), with the involvement of family members and caregivers, older people will be encouraged to use the TUI application.

Future work should also focus on improving the design of the Tangible Cup. In the first iteration in the design and development of the Tangible Cup, P6 suggested that the 'buttons' (which were later modified and became coasters) should work not only with the cup (which was later modified and became a cup attachment) but also other intuitive gestures. It was observed that some of the participants tried to touch the cup coasters while performing the testing tasks given to them. Multimodality can ensure that the diversity of older people is addressed (Teixeira et al., 2012; Tellioğlu et al., 2012). Some older people consider touch gestures as intuitive, while other might have difficulty performing touch gestures due to restricted muscle control or difficulty in understanding the GUI elements on touch devices.

Customization can be a helpful TUI design for older people. In iteration II, there were two suggestions for adopting a customization feature (i.e., the ringing sound and the video feature). During usability testing, P6 commented that the ringing sound was too sharp for her liking. The ringing sound should be able to be customized so that users can choose the ringing sound they prefer. Video chat is another customizable feature. It can be an option for older users who want to use it. After the users have been utilizing the Tangible Cup for some time, they might want to use the video chat feature to see each other. As found in the empirical study, some participants commented that they considered developing friendships further and meeting other users in person. The customized video chat feature could, therefore, be suitable for users who would like to utilize it. Angelini et al. (2016) used a window as a TUI object, and video chat was the main function of their TUI application. The results show that the video chat feature adopted in a TUI window can facilitate older people's social interactions.

Another improvement includes the automation feature. Older people might suffer from age-related declines in memory and, therefore, tend to forget things (Craik, 1994; Rodríguez-Fórtiz et al., 2016). Automation can assist older people while using tele-homecare, as demonstrated in a study conducted by Nourizadeh et al. (2009). In the future, automation features, such as automatically logging out older users after a long period of inactivity, should be implemented. This can help them when they do not log out correctly or forget to do so. As shown in the empirical study, some of the participants did not log out by placing the cup attachment on the *log out* coaster. Instead, they only pressed the power button and turned off the screen, thinking that they had logged out. The automation feature should also include turning on the volume for older users when they have accidentally lowered or switched it off.

In the empirical study, it was found that the calling application did not ring on the caller's side when the caller was making the call. This is a usability problem that confused the participants. Although they could see on the screen that they were calling (see Figure 19), they were unsure whether they were doing it correctly. A similar issue was reported for the battery level indicator on the cup attachment, as well as the lack of an indicator when they had missed a call. These usability problems can be related to one of the universal design principles: perceptible information. According to Story (1998, p. 8), the center for Universal Design of North Carolina State University defines perceptible information as "the design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.'

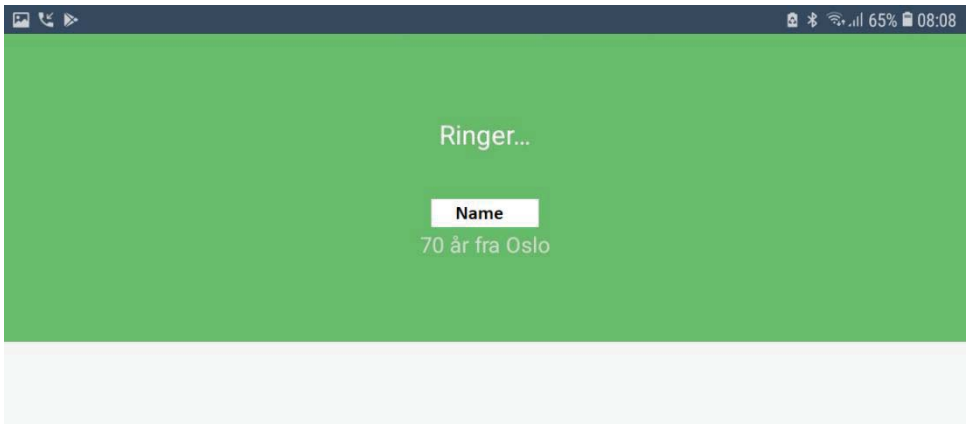

Figure 19. Call-making screen in the Tangible Cup's calling application.

Finally, as mentioned in Section 7.6, a validation study of the OPQOL questionnaire has been conducted. The results are still under analysis, and various themes, such as 'relevance and applicability,' 'formulation and scale,' 'consistency,' and 'subjectivity' have been identified. The theme 'relevance and applicability' focuses on the relevance and applicability of statements in the original OPQOL questionnaire to older people living in Norway. Two statements that received most reactions from the participants are statement 34 and 35: 'Religion, belief or philosophy is important to my quality of life' and 'Cultural/religious events/festivals are important to my quality of life.' Most of the participants mentioned the irrelevance of these elements for them in their quality of life, as they were not religious.

> *Yes, one can think of the cultural and religious stuff there (referring to the questionnaire) if it had any influence . . . And for me, then, I don't go to the church or something like that, but I have my childhood's faith there. And about cultural stuff, I do like to go to look*

at art exhibitions, I like to go to the city and look around, and I feel like I am a bit here and there. I am a bit in the middle there.

The results of this study will be presented in an upcoming publication.

8 Conclusions

To conclude the doctoral research work, the overarching main research goal shall be reflected upon; how TUI can impact home-dwelling older people's technology acceptance and quality of life by enhancing their social interactions? From the empirical study, 12 out of 16 participants improved their technology acceptance scores on the TAM questionnaire. Although no statistically significant changes were observed in the participants' OPQOL scores, the enjoyment they experienced while using the Tangible Cup for social interactions was observed and captured in the qualitative data. Some participants managed to have enjoyable conversations with others despite the challenges encountered when using the Tangible Cup. They could consider whether to develop the friendship further and meet in person. With the use of the Tangible Cup, some improved their 'leisure and activity' scores on the OPQOL. These findings indicate that the TUI impacted the participants' technology acceptance and quality of life by fostering social interactions.

All the participants agreed that the Tangible Cup has potential. They reflected on the characteristics of the older user target group that can benefit from using it. Older people who have no or few ICT skills, might be physically limited, struggle with performing touch gestures, are not good at finding things to do, and have restricted mobility are most likely to benefit from using the Tangible Cup. The participants also suggested various ways these older people could be approached, such as by visiting senior centers, speaking with healthcare personnel and caregivers, as well as the friends and family members of older people.

Older users' involvement and user empowerment have been demonstrated throughout the whole process of implementing the Tangible Cup. Throughout the process, TUI designs that could be suitable for older users and approaches that could be used when involving older people in designing a TUI for their use were gathered as lists of lessons learned. These lessons learned can serve as valuable guidelines that contribute to implementing TUI applications suitable for older people. The compatibility of TUI applications with older people's daily life and their diversity, as well as providing necessary instructions and automated functions, should be considered when designing TUI applications for this population. These designs could affect older users' technology acceptance and use, thereby enhancing their quality of life.

To the best of our knowledge, this is the first research project to involve designing and developing a TUI with and for older people and evaluating a TUI application with older people over a long period of time. The research shows that TUI applications have the potential to enhance older people's technology acceptance, social interactions, and quality of life. This study attempts to address the knowledge gaps identified during the systematic literature review, including the lack of (i) older users' involvement throughout the whole research process, (b) evaluation in relation to social interactions, (c) longitudinal studies and interdisciplinary collaboration when conducting research on TUI for older people's social interactions, (d) guidelines for developing TUI for older people, and most importantly, (e) research on using TUI to enhance older people's social interactions.

While this interdisciplinary research brings together the perspectives from the health sciences and human-computer interaction, the outcomes show that the research is more complex than simply bringing these two perspectives together. The use of TUI applications by older people for social interactions is related to their individual characteristics and social behavior. Furthermore, the impact on quality of life is multidimensional. OPQOL has many dimensions, and each dimension might relate to another. The social interactions performed using Tangible Cup were believed to relate the most to social relationships and participations. However, due to the diversity of the participants in relation to their ICT skills and existing social life, the results indicate that it was strongly related to the participants' leisure activity (i.e. voluntary activity).

In terms of the implications for practice, the findings of this interdisciplinary research may contribute to adding new knowledge of TUI design to improve older people's technology acceptance, social interactions, and quality of life. Designers and developers, clinicians and practitioners, policymakers, and older people can utilize this new knowledge. For designers and developers, the research has demonstrated the importance of older users' involvement and empowerment, as well as usability testing and evaluation. A better approach to designing TUI with and for older people and guidelines for more intuitive TUI designs that can benefit older people have been suggested.

Clinicians and practitioners of elderly healthcare can be informed about the potential of TUI to enhance older people's social interactions, technology acceptance, and quality of life. They provide health-related services to older people, who may be more likely to follow their

healthcare providers' advice. Most importantly, the findings of this research can, hopefully, instill positive attitudes toward ICT use among clinicians and practitioners.

The results of this research emphasize the importance of interdisciplinary collaboration between people working in healthcare- and technology-related fields. These two fields are strongly related; older people's quality of life and health can be enhanced with the help of ICT, but the design of ICT has to consider their needs. Otherwise, it will neither be accepted nor used by older people. The lessons learned in designing a TUI or ICT in general with and for older people, along with the outcomes of older people using the TUI application, might be of importance to policymakers while promoting health technology and implementing digitalization in the healthcare sector.

Finally, the research might inform older people about the potential of using a TUI application or ICT in general. If they are more aware of the potential, they might be persuaded to be more positive in accepting and using ICT. As a result, they can have better social interactions, a more active social life, improved social relationships, and hence, a better quality of life.

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10 Appendix

10.1 Appendix I: Article published in the magazine *Pensjonisten* (The Pensioner)

Av unge for eldre

Velferdsteknologi kan bidra til eldres selvstendighet og samfunnsdeltakelse, og gjøre deres livskvalitet bedre. Ivrige og kreative studenter jobber med å utvikle nye digitale løsninger spesielt tilpasset eldre.

Tekst: SISSEL FANTOFT *Foto:* ODA HVEEM

Det internasjonale masterstudiet i universell utforming av IKT (informasjons- og kommunikasjonsteknologi) ved Høgskolen i Oslo og Akershus er unikt i verdenssammenheng. Studiet handler om å gjøre IKT-systemer og -tjenester tilgjengelige for flest mulig, uavhengig av datautstyr, situasjoner og funksjonsevne.

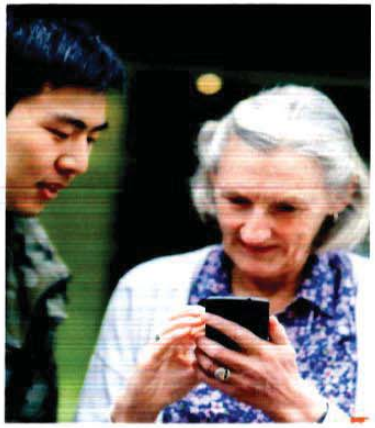
– Hvert år har vi flere masterprosjekter som er rettet mot eldre, for eksempel studenter som utvikler og tester app'er for eldre, eller undersøker utfordringer med digitale systemer og tjenester som eldre møter, forteller professor Weiqin Chen ved Institutt for informasjonsteknologi ved HiOA.

Hun har selv utviklet digital teknologi for eldre i prosjektet «Remembering the older days».

– Prosjektet handler om å hjelpe eldre med å snakke og huske ting fra da de var unge, forklarer hun.

Chen har tidligere jobbet som frivillig med å undervise eldre i å bruke datamaskin.

Nan Li viser høyskolelektor Siri Kessel mobilspillet han har utviklet spesielt beregnet på eldre brukere.



> Mange eldre blir sittende hjemme og se på tv etter at de er pensjonister. Derfor er det fint å kunne utvikle et spill som både gir underholdning og sosial kontakt,
>
> Weiqin Chen

– Der fikk jeg veldig god kontakt med kursdeltakerne og deres venner. Jeg ble kjent med deres hverdag, utfordringer og aktiviteter. Jeg har også selv eldre foreldre som inspirerer meg til å finne løsninger for å gjøre deres hverdag bedre, sier hun.

Fantastiske reaksjoner. Det er stor interesse blant masterstudentene for å jobbe med velferdsteknologi for eldre.

– Å arbeide med velferdsteknologi for eldre, gir mening til deres masterprosjekter. De kan relatere det de gjør med eldre i sin egen familie og sette seg inn i utfordringer som de opplever på nært hold. Å løse et reelt problem, og å se nytten av løsningene, er motiverende, sier Chen.

Både masterstudent Nan Li og doktorgradsstipendiat Way-Kat Bong jobber med å utvikle IKT-løsninger for eldre.

– Min masteroppgave går ut på å designe et mobilspill – Gobang. Spillet er evaluert av brukere på 60+ i Kina, og reaksjonene er fantastiske. De som deltok følte at deres livskvalitet ble svært forbedret gjennom å spille spillet, forteller Li. Han har en bachelorgrad fra Communication University of China i Beijing og er andreårs heltidsstudent på masterstudiet i universell utforming av IKT ved HiOA.

Spillet kan spilles av én eller flere deltakere, og mange av testbrukerne opplyste at de spilte med både kjente og ukjente.

– De fikk rett og slett nye venner gjennom spillet. Mange eldre blir sittende hjemme og se på tv etter at de er pensjonister. Derfor er det fint å kunne utvikle et spill som både gir underholdning og sosial kontakt, sier han.

Kommunikasjon via kopp. Way-Kiat Bong var i det første masterkullet på studiet, og er nå i gang med sin doktorgradsavhandling.

– Min masteroppgave handlet om å utvikle en app for meldingstjenester. Mange eldre deltar ikke på sosiale medier som Facebook, og bruker dermed ikke meldingstjenesten Messenger. Jeg utviklet et program som gjør det enklere for eldre å bruke direktemeldinger, forteller han.

Bong er helt i oppstarten med doktorgradsavhandlingen, men planen er å utvikle en kopp som et kommunikasjonsverktøy.

– Mange eldre synes det er vanskelig å bruke en smarttelefon, og jeg tenkte at det første man gjør om morgenen er å ta seg en kopp kaffe. Hva om man kunne bruke koppen til å snakke med andre, og kanskje også sende bilder og meldinger med? sier han.

Både Nan Li og Way-Kiat Bong synes det er inspirerende å jobbe med løsninger spesielt rettet mot eldre.

– Vi blir jo selv eldre, og en dag er det vi som sliter med å henge med i den lynraske teknologiske utviklingen. Det er viktig å inkludere eldre så tidlig som mulig og utvikle løsninger på deres premisser, istedenfor å tvinge dem til å lære alt som unge holder på med, sier Way-Kiat Bong.

Har du lyst til å delta som testbruker i Way-Kiat Bongs doktorgradsprosjekt? Ta kontakt med ham på: **way-kiat.bong@hioa.no**

10.2 Appendix II: Consent form for the Tangible Cup's design and development study (Article II)

Forespørsel om deltakelse i PhD forskningsprosjektet

"Promoting elderly social activities using tangible cup"

(Støtte til eldre sosialaktiviteter med en håndgripelig samhandlende kopp)

Bakgrunn og mål

Dette er et spørsmål til deg om å delta i forskningsprosjekt «*Støtte til eldre sosialaktiviteter med en håndgripelig samhandlende kopp*». Mange eldre bor alene og for dem kan teknologi brukes til å få kontakt med andre mennesker. Dette kan bidra til at hverdagen oppleves hyggeligere. For å sikre at eldre mennesker kan holde kontakt med andre og redusere deres opplevelse av ensomhet, er det viktig at kommunikasjonsteknologien er lett å bruke og oppleves nyttig av eldre brukere.

Dette forskningsprosjektet vil utvikle en brukervennlig enkel velferdsteknologi for å oppmuntre eldre mennesker til å holde seg sosialt aktive og opprettholde god kontakt med andre mennesker. Det vil si en håndgripelig samhandlende kopp som kan fungere som et kommunikasjonsverktøy, og samtidig er en kopp som brukes hverdag til te eller kaffe.

Det overordnede målet er å fremme ny kunnskap om hvordan forholdene legges til rette for at eldre mennesker kan være sosialt aktive. Forskningsprosjektet er en PhD studie som gjennomføres av institutt for helsefag og informasjonsteknologi ved Høgskolen i Oslo og Akershus. Ansvarlig virksomhet for prosjektet er Høgskolen i Oslo og Akershus. Prosjektledere er professor Weiqin Chen og professor Astrid Bergland, og daglig ansvarlig for prosjektet er doktorgradsstipendiaten Way Kiat Bong. Prosjektet er finansiert av Høgskolen i Oslo og Akershus.

Hva innebærer deltakelse i prosjektet?

Det første som vil skje om du takker ja til å delta i prosjektet er at doktorgradsstipendiaten vil forta et intervjue med testing med deg. Bakgrunnen for dette er å få frem dine synspunkter på hvordan velferdsteknologi i dette tilfelle en samhandlende kopp bør utvikles for å fremme kommunikasjon mellom deg og andre mennesker. Intervjuet, som vil bli ledet av forskeren, vil det legges vekt på å få frem dine synspunkter for å løfte frem dine erfaringer og tanker, både positive og negative.

Intervjuet med testing vil vare i 1 til 1 ½ timer.

Det vil dreie seg om

- Hvordan skal den håndgripelige interaktive koppen bli utformet?
- Hvordan skal den håndgripelige interaktive koppen brukes?

Intervjusamtalene vil bli tatt opp på bånd og lagret som lydfiler. I prosjektet vil vi innhente opplysninger om deg som kjønn, alder, bostatus, bruk av ganghjelpemidler, tjenestebehov i hjemmet. Innhentet persondata, materiale fra intervjuer og helseopplysninger vil oppbevares avidentifisert. Dette innebærer at forskningsdata og persondata vil lagres sikkert hver for seg.

Mulige fordeler og ulemper

Å bidra til et samfunn som tilrettelegger for sosiale aktive eldre regnes som en viktig kvalitetsindikator på en samfunn det er godt å leve i. Som deltaker i prosjektet vil du bidra til å belyse hvilke erfaringer og forståelser eldre selv har med hensyn til brukervennlig og hensiktsmessig velferdsteknologi. Målet med dette prosjektet er å fremme kunnskap om hva som former god og brukervennlig velferdsteknologi som motiverer til meningsfull kommunikasjon med andre ved å innhente dine synspunkter. Dine opplevelser, reaksjoner og synspunkter vil bidra til å belyse hva som er brukervennlig og hensiktsmessig velferdsteknologi.

Ulempen kan være at forskeren bruker din tid og forskerens tilstedeværelse virker påtrengende. Hvis forskerens tilstedeværelse virker negativt, vil imidlertid forskeren avslutte intervjuet og trekke seg tilbake.

Hva skjer med informasjonen om deg?

Alle personopplysninger vil bli behandlet konfidensielt.

Opptak av gruppeintervjuene vil bli lagret som lydfiler på et eget område på en dataserver ved Høgskolen i Oslo og Akershus. Det samme vil gjøres med notater og analyser av datamaterialet. Kun forskere vil ha tilgang til dette området. Deltakernes navn, alder og kontaktinformasjon, vil lagres i et dokument, som beskyttes med passord, på det samme området. Kun stipendiaten har tilgang til navnelisten.

Deltakerne vil ikke kunne bli gjenkjent i artikler hvor forskningsresultatene offentliggjøres. Det er mulig at anonymiserte sitater fra intervjuene vil bli brukt i slike artikler. Prosjektet skal etter planen avsluttes i desember 2019. Da vil lydopptak fra fokusgruppene bli slettet.

Frivillig deltakelse

Det er frivillig å delta i studien. Du kan når som helst trekke ditt samtykke til deltakelse, uten å oppgi noen grunn. Dersom du trekker deg, vil alle opplysninger om deg bli anonymisert.

Ønsker du å delta i gruppeintervju eller har spørsmål til studien, ta kontakt med forskeren:

- Way Kiat Bong, stipendiat: e-post: Way-Kiat.Bong@hioa.no Tlf: 96724429

Samtykke til egen deltakelse i studien

Jeg har mottatt informasjon om studien, og er villig til å delta

☐ ***Jeg samtykker til å delta i et intervju i et intervjue med testing***

Dato: ……. ……
(Underskrift av prosjektdeltaker)

10.3 Appendix III: Semi-structured interview guide

- Pre-testing

7. Can you tell us about your social life? Are you satisfied with it?
8. Do you wish to have more people that you can talk to?
9. What is the best part of your social life?
10. What do you dislike the most about your social life?
11. How do you keep in touch with your friends and family?
12. How would you describe ‘a good life’?
13. What do think about calling to someone that you don’t know and talk to that person?
14. What are your experiences with using ICT? Mobile phones, computers, etc.
15. Do you have any problem?
16. In a scale of 1-10, 1 is the worst and 10 is the best, how would you rate your competency in using ICT?
17. In which way do you think ICT has contributed in your social life?
18. (Present the Tangible Cup and demonstrate how it works) Do you have any expectation in using this? What could you anticipate?
19. We might arrange ‘cup talk sessions’ for you guys the testers. When is it the best time for you to join such sessions?

- Mid-testing

1. Can you tell us about your experiences of using Tangible Cup?
2. Do you manage to call and talk to anyone? How many, if you remember?
3. What kind of problem do you have while using it?
4. Anything positive about this Tangible Cup?
5. Anything negative about this Tangible Cup?
6. What do you do when you are finish in using it? Can you show me?
7. How do you log out?
8. How has the Tangible Cup contributed in your life, when you think about your everyday from the moment you wake up until you go to bed again?
9. When do you usually use it?
10. How often do you use it?

11. Have you made any arrangement with the person you had talked to about when to call and talk for the next time? Could you consider doing it?
12. Do you carry Tangible Cup around the apartment/house when you use it? Where do you use it? Have you only used it at the kitchen table?
13. What do think about calling to someone that you don't know and talk to that person?
14. Have you noticed any changes in your social life after using Tangible Cup?
15. (If the person has talked to someone) Do you think you have made new friend(s) after using Tangible Cup?
16. Does any friend or family of yours know about this Tangible Cup? What do they think about it?

- Post-testing

17. Can you tell us about your experiences of using Tangible Cup?
18. Do you manage to call and talk to anyone? How many, if you remember?
19. How do you feel about the conversations that you have had?
20. How did you feel when you didn't manage to reach the other testers?
21. How did you feel when you received a call?
22. What kind of problem do you have in using Tangible Cup?
23. Anything positive about this Tangible Cup?
24. Anything negative about this Tangible Cup?
25. How has the Tangible Cup contributed in your life, when you think about your everyday from the moment you wake up until you go to bed again?
26. Do you think it is easy or difficult to use?
27. When do you usually use it?
28. How often do you use it?
29. Have you made any arrangement with the person you had talked to about when to call and talk for the next time? Could you consider doing it?
30. What do think about calling to someone that you don't know and talk to that person?
31. Do you take initiative to call to the others? Or do you wait for them to call you?
32. What do you think is the reasons they did not answer/call you?
33. Is there any time you cannot use the Tangible Cup? (on holiday, been ill, etc.)
34. Have you noticed any changes in your social life after using Tangible Cup?

35. (If the person has talked to someone) Do you think you have made new friend(s) after using Tangible Cup?
36. Does any friend or family of yours know about this Tangible Cup? What do they think about it?
37. Who do you think can be suitable in using Tangible Cup?
38. For those that are suitable in using Tangible Cup, how do you think the Tangible Cup can contribute in improving their life?
39. Will you recommend Tangible Cup to someone you really know?
40. Can you tell us the reasons why you recommend the others Tangible Cup?

10.4 Appendix IV: TAM questionnaire

We would like to ask a few questions about your use of digital communication tools. Kindly select the response that best describes you/your view. There are no right or wrong answers, but choose the answer that you think is the best.

(1) By using digital communication tools, I can have better social interactions with my friends.						
Strongly disagree (1)	Disagree (2)	Somewhat disagree (3)	Neither disagree nor agree (4)	Somewhat agree (5)	Agree (6)	Strongly agree (7)
(2) By using digital communication tools, I can have a better social life.						
Strongly disagree (1)	Disagree (2)	Somewhat disagree (3)	Neither disagree nor agree (4)	Somewhat agree (5)	Agree (6)	Strongly agree (7)

(3) By using digital communication tools, I can make new friends.

Strongly disagree (1)	Disagree (2)	Somewhat disagree (3)	Neither disagree nor agree (4)	Somewhat agree (5)	Agree (6)	Strongly agree (7)

(4) Interaction with digital communication tools is clear and understandable.

Strongly disagree (1)	Disagree (2)	Somewhat disagree (3)	Neither disagree nor agree (4)	Somewhat agree (5)	Agree (6)	Strongly agree (7)

(5) Interaction with digital communication tools does not require a lot of mental effort.

Strongly disagree (1)	Disagree (2)	Somewhat disagree (3)	Neither disagree nor agree (4)	Somewhat agree (5)	Agree (6)	Strongly agree (7)

(6) I find digital communication tools easy to use.

Strongly disagree (1)	Disagree (2)	Somewhat disagree (3)	Neither disagree nor agree (4)	Somewhat agree (5)	Agree (6)	Strongly agree (7)

(7) I find it easy to learn to use digital communication tools.

Strongly disagree (1)	Disagree (2)	Somewhat disagree (3)	Neither disagree nor agree (4)	Somewhat agree (5)	Agree (6)	Strongly agree (7)

(8) I find it enjoyable to use digital communications tools.

Strongly disagree (1)	Disagree (2)	Somewhat disagree (3)	Neither disagree nor agree (4)	Somewhat agree (5)	Agree (6)	Strongly agree (7)

(9) I find it exciting to use digital communications tools.						
Strongly disagree (1)	Disagree (2)	Somewhat disagree (3)	Neither disagree nor agree (4)	Somewhat agree (5)	Agree (6)	Strongly agree (7)
(10) I find it pleasant to use digital communications tools.						
Strongly disagree (1)	Disagree (2)	Somewhat disagree (3)	Neither disagree nor agree (4)	Somewhat agree (5)	Agree (6)	Strongly agree (7)
(11) I find it interesting to use digital communications tools.						
Strongly disagree (1)	Disagree (2)	Somewhat disagree (3)	Neither disagree nor agree (4)	Somewhat agree (5)	Agree (6)	Strongly agree (7)

(12) I would use digital communication tools.						
Strongly disagree (1)	Disagree (2)	Somewhat disagree (3)	Neither disagree nor agree (4)	Somewhat agree (5)	Agree (6)	Strongly agree (7)
(13) I use digital communication tools very often.						
Strongly disagree (1)	Disagree (2)	Somewhat disagree (3)	Neither disagree nor agree (4)	Somewhat agree (5)	Agree (6)	Strongly agree (7)
(14) Using digital communication tools is compatible with most aspects of my social life.						
Strongly disagree (1)	Disagree (2)	Somewhat disagree (3)	Neither disagree nor agree (4)	Somewhat agree (5)	Agree (6)	Strongly agree (7)

(15) Using digital communication tools fits my life style.						
Strongly disagree (1)	Disagree (2)	Somewhat disagree (3)	Neither disagree nor agree (4)	Somewhat agree (5)	Agree (6)	Strongly agree (7)
(16) Using digital communication tools fits well with the way I socialize with others.						
Strongly disagree (1)	Disagree (2)	Somewhat disagree (3)	Neither disagree nor agree (4)	Somewhat agree (5)	Agree (6)	Strongly agree (7)
(17) Using digital communication tools is a good idea.						
Strongly disagree (1)	Disagree (2)	Somewhat disagree (3)	Neither disagree nor agree (4)	Somewhat agree (5)	Agree (6)	Strongly agree (7)

(18) I am positive towards digital communication tools.						
Strongly disagree (1)	Disagree (2)	Somewhat disagree (3)	Neither disagree nor agree (4)	Somewhat agree (5)	Agree (6)	Strongly agree (7)
(19) I feel confident about learning to use digital communication tools.						
Strongly disagree (1)	Disagree (2)	Somewhat disagree (3)	Neither disagree nor agree (4)	Somewhat agree (5)	Agree (6)	Strongly agree (7)
(20) I feel confident about using digital communication tools.						
Strongly disagree (1)	Disagree (2)	Somewhat disagree (3)	Neither disagree nor agree (4)	Somewhat agree (5)	Agree (6)	Strongly agree (7)

(21) I have the necessary skills for using digital communication tools.						
Strongly disagree (1)	Disagree (2)	Somewhat disagree (3)	Neither disagree nor agree (4)	Somewhat agree (5)	Agree (6)	Strongly agree (7)

10.5 Appendix V: OPQOL questionnaire

This questionnaire is about your quality of life. The information that you give will help us in finding out your life. Each question should be answered with ticking a cross (x) at the box that suits you the best. If you are uncertain about what you should choose, kindly answer the best you can.

Older People's Quality of Life Questionnaire (OPQOL-35*)*					
We would like to ask you about your quality of life: Please tick one box in each row. There are no right or wrong answers. Please select the response that best describes you/your views.					
1	Thinking about both the good and bad things that make up your quality of life, how would you rate the quality of your life as a whole?				
	Very good	Good	Alright	Bad	Very bad
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]
	Please indicates the extent to which you agree or disagree with each of the following statements				
Life Overall					
1	I enjoy my life overall				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]

2	I am happy much of the time				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]
3	I look forward to things				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]
4	Life gets me down				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]
Health					
5	I have a lot of physical energy				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]

6	Pain affects my well-being				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]
7	My health restricts me looking after myself or my home				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]
8	I am healthy enough to get out and about				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]
Social relationships					
9	My family, friends or neighbours would help me if needed				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]

10	I would like more companions or contact with other people				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]
11	I have someone who gives me love and affection				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]
12	I'd like more people to enjoy life with				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]
13	I have my children around which is important				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]

Independence, control over life, freedom					
14	I am healthy enough to have my own independence				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]
15	I can please myself what I do				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]
16	The cost of things compared to my pension/income restricts my life				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]
17	I have a lot of control over the important things in my life				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]

Home and neighbourhood					
18	I feel safe where I live				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]
19	The local shops, services and facilities are good overall				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]
20	I get pleasure from my home				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]
21	I find my neighbourhood friendly				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]

Psychological and emotional well-being					
22	I take life as it comes and make the best of things				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]
23	I feel lucky compared to most people				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]
24	I tend to look on the bright side				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]
25	If my health limits social/leisure activities, then I will compensate and find something else I can do				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]

Financial circumstances					
26	I have enough money to pay for household bills				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]
27	I have enough money to pay for household repairs or help needed in the house				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]
28	I can afford to buy what I want to				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]
29	I cannot afford to do things I would enjoy				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]

Leisure and activities					
30	I have social or leisure activities/hobbies that I enjoy doing				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]
31	I try to stay involved with things				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]
32	I do paid or unpaid work or activities that give me a role in life				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]
33	I have responsibilities to others that restrict my social or leisure activities				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]

34	Religion, belief or philosophy is important to my quality of life				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]
35	Cultural/religious events/festivals are important to my quality of life				
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
	[1] [ ]	[2] [ ]	[3] [ ]	[4] [ ]	[5] [ ]

10.6 Appendix VI: Approval from NSD

NSD NORSK SENTER FOR FORSKNINGSDATA

NSD sin vurdering

Prosjekttittel

Promoting elderly social activities using tangible cup

Referansenummer

253545

Registrert

21.08.2018 av Way Kiat Bong - wayki@oslomet.no

Behandlingsansvarlig institusjon

OsloMet - storbyuniversitetet / Fakultet for teknologi, kunst og design / Institutt for informasjonsteknologi

Prosjektansvarlig (vitenskapelig ansatt/veileder eller stipendiat)

Way Kiat Bong, wayki@oslomet.no, tlf: 96724429

Type prosjekt

Forskerprosjekt

Prosjektperiode

15.11.2018 - 31.12.2019

Status

10.10.2018 - Vurdert

Vurdering (1)

10.10.2018 - Vurdert

Our assessment is that the processing of personal data in this project will comply with data protection legislation, presupposing that it is carried out in accordance with the information given in the Notification Form and attachments, as well as the dialogue with NSD. Everything is in place for the processing to begin.

NOTIFY CHANGES
If you intend to make changes to the processing of personal data in this project it may be necessary to notify NSD. This is done by updating the Notification Form. On our website we explain which changes must be notified. Wait until you receive an answer from us before you carry out the changes.

TYPE OF DATA AND DURATION
The project will be processing special categories of personal data until 31.12.2019.

LEGAL BASIS
The project will gain consent from data subjects to process their personal data. We find that consent will

meet the necessary requirements under art. 4 (11) and 7, in that it will be a freely given, specific, informed and unambiguous statement or action, which will be documented and can be withdrawn.

The legal basis for processing personal data is therefore explicit consent given by the data subject, cf. the General Data Protection Regulation art. 6.1 a), cf. art. 9.2 a), cf. the Personal Data Act § 10, cf. § 9 (2).

PRINCIPLES RELATING TO PROCESSING PERSONAL DATA
NSD finds that the planned processing of personal data will be in accordance with the principles under the General Data Protection Regulation regarding:
- lawfulness, fairness and transparency (art. 5.1 a), in that data subjects will receive sufficient information about the processing and will give their consent
- purpose limitation (art. 5.1 b), in that personal data will be collected for specified, explicit and legitimate purposes, and will not be processed for new, incompatible purposes
- data minimisation (art. 5.1 c), in that only personal data which are adequate, relevant and necessary for the purpose of the project will be processed
- storage limitation (art. 5.1 e), in that personal data will not be stored for longer than is necessary to fulfil the project's purpose

THE RIGHTS OF DATA SUBJECTS
Data subjects will have the following rights in this project: transparency (art. 12), information (art. 13), access (art. 15), rectification (art. 16), erasure (art. 17), restriction of processing (art. 18), notification (art. 19), data portability (art. 20). These rights apply as long as the data subject can be identified in the collected data.

NSD finds that the information that will be given to data subjects about the processing of their personal will meet the legal requirements for form and content, cf. art. 12.1 and art. 13.
We remind you that if a data subject contacts you about their rights, the data controller has a duty to reply within a month.

FOLLOW YOUR INSTITUTION'S GUIDELINES
NSD presupposes that the project will meet the requirements of accuracy (art. 5.1 d), integrity and confidentiality (art. 5.1 f) and security (art. 32) when processing personal data.

A transcription assistant will be used in the project. The transcription assistant will be a data processor for the project. NSD presupposes that the processing of personal data by a data processor meets the requirements under the General Data Protection Regulation arts. 28 and 29.

To ensure that these requirements are met you must follow your institution's internal guidelines and/or consult with your institution (i.e. the institution responsible for the project).

FOLLOW-UP OF THE PROJECT
NSD will follow up the progress of the project at the planned end date in order to determine whether the processing of personal data has been concluded.

Good luck with the project!

Contact person at NSD: Lise Haveraaen
Data Protection Services for Research: +47 55 58 21 17 (press 1)

10.7 Appendix VII: Consent form for the empirical study (Article III and IV)

Forespørsel om deltakelse i PhD forskningsprosjektet

"Promoting elderly social activities using tangible cup"

(Støtte til eldre sosialaktiviteter med en håndgripelig samhandlende kopp)

Bakgrunn og mål

Dette er et spørsmål til deg om å delta i forskningsprosjekt «Bidrag til økning av eldre menneskers sosial aktiviteter *ved hjelp av en håndgripelig samhandlende kopp*». Du blir invitert til å delta i dette prosjektet siden du har deltatt et annet forskningsprosjekt ved OsloMet som heter «Livskvalitet, smerte, mestring, ernæringsstatus, fysisk, psykisk og sosial funksjon hos brukere av seniorsentrene». Basert på resultatet derfra synes vi at du kunne passe i dette prosjektet.

For de eldre kan en mer brukervennlig teknologi oppmuntrer dem til å både få og ta kontakt med andre. Dette kan bidra til at hverdagen oppleves hyggeligere. For å sikre at eldre mennesker kan holde kontakt med hverandre, er det viktig at kommunikasjonsteknologien er lett å bruke og oppleves nyttig av eldre brukere.

Dette forskningsprosjektet vil utvikle og teste en 'tangible cup' (håndgripelig samhandlende kopp) for å oppmuntre eldre mennesker til å holde seg sosialt aktive og opprettholde god kontakt med andre mennesker samt bidra til sosial deltakelse blant andre eldre. Det vil si den håndgripelig samhandlende koppen skal fungere som et kommunikasjonsverktøy, og samtidig er en kopp som brukes hverdag til te eller kaffe. Tangible cup brukes til å kontrollere en ringe-app på et nettbrett. Ved å bruke appen kan brukerne ringe til andre som har lyst å prate med noen andre som har felles interesser.

Det overordnede målet er å fremme ny kunnskap om hvordan forholdene legges til rette for at eldre mennesker kan være sosialt aktive og delta sosialt samt oppleve mindre ensomhet. Forskningsprosjektet er en PhD studie som gjennomføres av institutt for helsefag og informasjonsteknologi ved OsloMet – storbyuniversitetet. Ansvarlig virksomhet for prosjektet er OsloMet – storbyuniversitetet. Prosjektledere er professor Weiqin Chen og professor Astrid Bergland, og daglig ansvarlig for prosjektet er doktorgradsstipendiaten Way Kiat Bong. Prosjektet er finansiert av OsloMet – storbyuniversitetet.

Hva innebærer deltakelse i prosjektet?

Prosjektet skal samle informasjon om deltakernes sosialt liv og livskvalitet. Det første som vil skje om du takker ja til å delta i prosjektet er at du vil få en håndgripelige samhandlende kopp og blir bedt om å teste og bruke den for tre måneder. På begynnelsen, midten og slutten av testingen vil doktorgradsstipendiaten eller forskningsassistenten forta et intervjue med deg. I tillegg vil du bedt om å fylle et spørreskjema knyttet til livskvalitet og et om bruken av digitale kommunikasjonsmidler. Bakgrunnen for dette er å få frem dine synspunkter på ditt sosialt liv og hvordan den samhandlende kopp kunne brukes som et kommunikasjonsverktøy mellom deg og andre mennesker.

Det å fylle spørreskjema samt intervjuet vil vare i 1 til 1 ½ timer.

Det vil dreie seg om

- Hvordan opplever du i å bruke den håndgripelige interaktive koppen?
- Hvordan har koppen påvirket sosialt livet ditt?

Intervjusamtalene vil bli tatt opp på bånd og lagret som lydfiler. I prosjektet vil vi innhente opplysninger om deg som kjønn, alder, bostatus, tjenestebehov i hjemmet, IP adresse og telefonnummer. Innhentet persondata, materiale fra intervjuer og helseopplysninger vil oppbevares avidentifisert. Dette innebærer at forskningsdata og persondata vil lagres sikkert hver for seg.

Mulige fordeler og ulemper

Å bidra til et samfunn som tilrettelegger for sosiale aktive eldre regnes som en viktig kvalitetsindikator på en samfunn det er godt å leve i. Som deltaker i prosjektet vil du bidra til

å belyse hvilke erfaringer og forståelser eldre selv har med hensyn til brukervennlig og hensiktsmessig velferdsteknologi. Målet med dette prosjektet er å fremme kunnskap om hva som former god og brukervennlig velferdsteknologi som motiverer til meningsfull kommunikasjon med andre ved å innhente dine synspunkter. Dine opplevelser, reaksjoner og synspunkter vil bidra til å belyse hva som er brukervennlig og hensiktsmessig velferdsteknologi.

Ulempen kan være at forskeren bruker din tid og forskerens tilstedeværelse virker påtrengende. Hvis forskerens tilstedeværelse virker negativt, vil imidlertid forskeren avslutte intervjuet og trekke seg tilbake.

Hva skjer med informasjonen om deg?

Alle personopplysninger vil bli behandlet konfidensielt.

Opptak av gruppeintervjuene vil bli lagret som lydfiler på et eget område på en dataserver ved OsloMet – storbyuniversitetet. Det samme vil gjøres med notater og analyser av datamaterialet. Kun forskere vil ha tilgang til dette området. Deltakernes navn, alder og kontaktinformasjon, vil lagres i et dokument, som beskyttes med passord, på det samme området. Kun stipendiaten har tilgang til navnelisten.

Deltakerne vil ikke kunne bli gjenkjent i artikler hvor forskningsresultatene offentliggjøres. Det er mulig at anonymiserte sitater fra intervjuene vil bli brukt i slike artikler. Prosjektet skal etter planen avsluttes i desember 2019. Da vil lydopptak fra intervjuene bli slettet. De samlende opplysningene behandles manuelt på en fysisk isolert maskinvare tilhørende universitetet og det er prosjektansvarlig og databehandler (dvs transkriptør) som har tilgang til dem.

Frivillig deltakelse

Det er frivillig å delta i studien. Du har rett til innsyn i hvilke personopplysninger som er registrert om deg, å få rettet personopplysninger om deg, få slettet personopplysninger om deg, få utlevert en kopi av dine personopplysninger (dataportabilitet) og sende klage til personvernombudet eller Datatilsynet om behandlingen av dine personopplysninger. Du kan når som helst trekke ditt samtykke til deltakelse, uten å oppgi noen grunn. Dersom du trekker deg, vil alle opplysninger om deg bli **anonymisert**.

Ønsker du å delta i gruppeintervju eller har spørsmål til studien, eller ønsker å benytte deg av dine rettigheter ta kontakt med:

- Way Kiat Bong, stipendiat: e-post Way-Kiat.Bong@oslomet.no Tlf: 96724429
- NSD – Norsk senter for forskningsdata AS: epost personverntjenester@nsd.no Tlf: 5558 2117.

Samtykke til egen deltakelse i studien

Jeg har mottatt informasjon om studien, og er villig til å delta

☐ ***Jeg samtykker til å delta i et intervju i et intervjue med testing***

Dato: ……. ……
(Underskrift av prosjektdeltaker)

11 Article I - IV

Article I:

Bong, W. K., Chen, W., & Bergland, A. (2018). Tangible user interface for social interactions for the elderly: a review of literature. *Advances in Human-Computer Interaction*.
DOI: **https://dx.doi.org/10.1155/2018/7249378**

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Advances in Human-Computer Interaction
Volume 2018, Article ID 7249378, 15 pages
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Review Article

Tangible User Interface for Social Interactions for the Elderly: A Review of Literature

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The global population is ageing rapidly. The ageing population faces not only the risk of health-related problems but also the challenge of social isolation and loneliness. While mainstream technology is designed to improve daily life, elderly people's unique needs are often neglected. These technology designs can be difficult for older adults to learn and use. Tangible user interface (TUI) gives physical form to digital information, with the aim of bridging the gap between the digital world and the physical world. Thus, it can be a more natural and intuitive interface for the older adults. The objective of this research is to review the existing research on TUI for enhancing the social interactions of elderly people. Results show that very little research has been published, given that the TUI concept was introduced 20 years ago. Our systematic literature review also resulted in several recommendations for future research, which includes getting elderly people involved in the process, from designing to evaluating the prototype and investigating the effect of TUI on older adults' social interactions and health.

1. Introduction

According to DESA, the United Nations Department of Economic and Social Affairs [1], the number of adults who are 60 and above will grow from 901 million to 1.4 billion between 2015 and 2030. This number is projected to grow to 2.1 billion by 2050 and 3.2 billion in 2100. Due to socioeconomic developments, people tend to live better, have better healthcare, and thus, are living longer [2]. Life expectancies are increasing, while fertility rates remain low, and this condition is expected to continue in the coming decades. However, evidence is scarce as to whether these added years are lived in good health and function [3, 4]. Thus, since the world population is ageing rapidly, it is essential to identify determinants of healthy ageing so one can maintain his or her function and preserve health as long as possible [5].

Healthy lifestyles have a strong association with healthy ageing and maintenance of social and physical function [6]. According to World Health Organization (WHO) [7], social well-being is one of the elements required for a person to be healthy. In Europe, at least one-third of the elderly people live alone [8], who tend to be socially excluded. This number is growing according to recent statistics [9]. Being socially active, which means having good social interactions, can contribute to our well-being and feelings of belonging, which makes us happy [10]. Social relationships are found to be a significant predictor of well-being across the course of life [11–13] which is perhaps particularly salient for older adults [14, 15].

While information and communication technologies (ICT) tools designed to improve daily life are expanding widely, the special needs of elderly people have always been neglected in the design of technology tools such as mobile applications and social media [16, 17]. Older adults might not be as good as younger people when it comes to physical and cognitive abilities, and every elderly person is different. As a result, older adults need a better design for interaction while using technology tools.

Tangible user interface (TUI) can be defined as an interface where everyday physical objects play a central role as both physical representations and controls for digital information [18, 19]. In short, TUI makes no distinction between "input" and "output." TUI offers an intuitive design that allows tactile manipulation and physical expressiveness

by coupling digital information with physical objects and environments [20]. It merges physical objects with digital information. By using physical objects to represent digital output, TUI eliminates the need to have intangible output devices such as monitors and speakers [21]. Thus, TUI has been identified by Spreicer [21] as having great potential to improve older adults' acceptance of technology acceptance. This can be a more natural, intuitive, and easier interaction for elderly people, which might also result in less cognitive and physical efforts required from them.

Therefore, TUI has potential to make technology tools more accessible to elderly people. The objective of our review is to gain an overview of the evidence. By conducting this systematic literature review, we wish to summarize the current research evidence where elderly people are involved in TUI design process and TUI has an impact on the social interactions of older adults. We identify possible shortcomings of the current research in this area and suggest improvements. This paper is organized as follows. After the Introduction, we present the background, covering loneliness and social interactions of older adults and TUI. We present methods and process of the literature review in Section 3, from planning, conducting a review, and studying the selection, to reporting on the review. Results are discussed in Section 4. In Sections 5 and 6, we present our recommendations and conclude the paper by reflecting on the process and outcome.

2. Background

2.1. Loneliness and Social Interactions of Elderly People. Loneliness can be defined as a feeling or emotional state of individuals who are dissatisfied with their social relationships. This dissatisfaction occurs when they face a difference between what they expect or want and what they get when it comes to their social lives [22]. Social interaction is defined as *"two or more autonomous agents co-regulating their coupling with the effect that their autonomy is not destroyed and their relational dynamics acquire an autonomy of their own. Examples: conversations, collaborative work, arguments, collective action, dancing and so on"* [23]. Thus, any form of socialization between two or more agents, for instance, between elderly people with their friends and families, health personnel, or even new people who they have never talked to, is considered as social interaction as long as it is done with their own will. Social interaction varies across gender and age [24]. Due to transitions in one's life cycle, for instance, from schooling to working then retirement, from being single to getting married, and so on, the social interaction changes.

Elderly people who are dissatisfied or inactive in their social interactions would feel lonely and socially isolated. Loneliness and social isolation among the ageing population are significant concerns as they have varied negative impacts on elderly people's health [25–31]. Socially disconnected older adults (e.g., having small social networks and infrequent participation in social activities) face the possibilities of having inferior physical and mental health because of being isolated [32]. Studies have also demonstrated associations between loneliness and diseases such as heart disease, hypertension, stroke, lung disease, and metabolic disorders [29]. Being active in social interaction can contribute in less cognitive decline and better physical well-being [24]. Thus, having good social interactions is essential, as active social lives can help maintain a good quality of life, health, and physical functioning [33, 34].

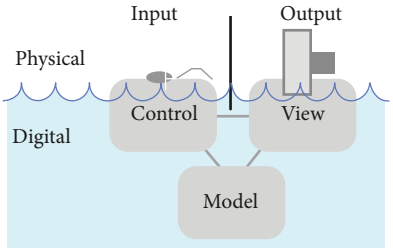

Figure 1: Interaction model of GUI: Model-view-control model from Smalltalk-80 [35].

Many studies have been conducted regarding the use of ICT tools to prevent or reduce the social isolation of elderly people, but the outcomes are ambiguous. Social isolation has been identified by Chen and Schulz [17] as an untested concept in these studies since most studies only evaluated loneliness, social network size, and social support. Thus, the effects of these ICT interventions on the overall perception of social isolation remain largely unknown. They also suggested that the ICT solutions are not "one for all." The benefits of ICT interventions to improve older adults' social interactions can only be maximized if the potential elderly users can be identified.

2.2. Tangible User Interface (TUI). Much of our daily life has become digitalized. From physical walk-in banks to electronic banking (e-banking), from abacus and physical calculator to calculator in computers and mobile phones, more of our physical surroundings are being replaced by the digital world. With the intention of rejoining the richness of physical world in Human Computer Interaction (HCI), Ishii and Ullmer [18] introduced the vision "Tangible Bits." By coupling digital information (bits) with everyday physical objects and architectural surfaces, the interaction between humans and digital information can be enhanced from its traditional Graphical User Interface (GUI).

The traditional GUI obtains input from control and displays the output in the forms of "digital representations" [19]. As illustrated in Figure 1, this interaction model was developed in conjunction with Smalltalk-80 programming language [35]. The difference between the traditional GUI interaction model and TUI is that TUI does not make a distinction between input and output (Figure 2).

According to Ullmer and Ishii [19], TUI has three main characteristics, as shown in Figure 2. They are as follows:

(1) Physical representations *(rep-p)* are computationally coupled to underlying digital information *(model)*.

(2) Physical representations embody mechanisms for interactive control *(control)*.

(3) Physical representations are perceptually coupled to actively mediated digital representations *(rep-d)*.

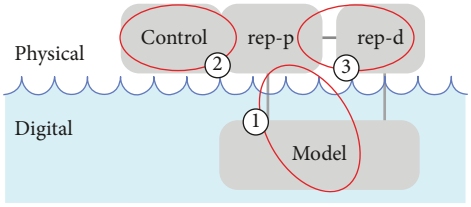

Figure 2: Interaction model of TUI by Ullmer and Ishii [19].

Besides that Ullmer and Ishii [19] suggest five types of tasks which TUI is good for. They are as follows:

(1) Information storage, retrieval, and manipulation.

(2) Information visualization.

(3) Modelling and simulation.

(4) Systems management, configuration, and control.

(5) Education, entertainment, and programming systems.

Tangible Bits aim to eliminate the gaps between the physical and digital world, as well as the foreground and background of human activities. Ishii and Ullmer [18] presented three key concepts of Tangible Bits:

(1) Interactive surfaces: surfaces such as walls, ceilings, doors, and windows are transformed into active surfaces between physical and digital worlds.

(2) The coupling of bits with graspable physical objects: everyday graspable objects such as cups, books, and cards are coupled with digital information.

(3) Ambient media for background awareness: ambient media such as sound, light, airflow, and water movement serve as the background interfaces for digital worlds where a human being can perceive them.

Due to its advantage in using haptic interaction to interact with the digital world, TUI has been used in fields such as learning, problem solving and planning, information visualization, tangible programming, entertainment, and social communication [36]. Urban Planning Workbench (Urp) was developed by Underkoffler and Ishii [37] as the first generation of TUI. Scaled physical models of buildings were used as representations of digital models of the buildings, so users can manipulate them physically to change location and simulate shadow, light reflection, and more.

From Urp, it is clear that collaboration, learning, and decision making though digital technology could be enhanced by having a human being physically touch and interact with the physical objects [38]. Although TUI provides an excellent platform for collaboration and makes users feel "situated" in the real world with digital information, it faces the problem of scalability and versatility [36]. The more digital information users must deal with, the more complex the TUI must be. Digital objects are easy to create and modify, but physical objects cannot be transformed as easily as digital objects.

3. Method and Results

The methodology of this review has been derived by referencing other published literature review and refers to the systematic literature review guidelines by Keele [39]. Our review methodology consists of three main phases.

3.1. Planning the Review. During this phase, we identified the needs for this literature review, which we clarified and presented in our introduction. To identify the gaps and give recommendations for future research directions [39, 40], we reviewed the state-of-the-art existing literature in this area. The research questions were generated accordingly, and they are listed as follows:

(1) How does TUI impact the social interactions of elderly people?

(2) Have elderly people been involved in the process of design and development of TUI prototype, and if so, in which way?

3.2. Conducting the Review. From the research questions, we identified three main search terms, and they were "elderly," "tangible user interface," and "social." Before performing the search, the inclusion and exclusion criteria were defined.

(1) The target group of the paper must be older adults who are generally above 50.

(2) Papers must focus on TUI.

(3) Papers must focus on the social aspect.

(4) Papers where TUI focuses on robot, mobile, computer and tablet-based applications, ambient intelligence, and smart homes are excluded. Our primary focus on TUI is using everyday objects and not a whole environment or unfamiliar object. Robot, mobile, computer and tablet-based applications, ambient intelligence, and smart homes do not fulfil the condition of using an everyday object as TUI. Mobile phones, computers, and tablets also have a certain level of difficulty in use for the elderly people. Both ambient intelligence and smart homes work as an environment and not a single object. Therefore, they are also excluded.

(5) Only published or peer-reviewed works are included. Dissertations and theses are excluded.

(6) Non-English papers are excluded.

The search was conducted from 20 June 2017 to 10 July 2017 by two researchers, separately. Four electronic databases recommended by Brereton et al. [41] and one by Keele [39] were used in performing the search. Combining the main search terms and inclusion and exclusion criteria, the generated search string was *elderly AND "tangible user interface" AND social AND NOT robot AND NOT "smart home" AND NOT "ambient intelligence"*. A supplement search using the same search string was conducted on Google Scholar (also recommended by Brereton et al. [41]) from 29 January 2018 to 31 January 2018.

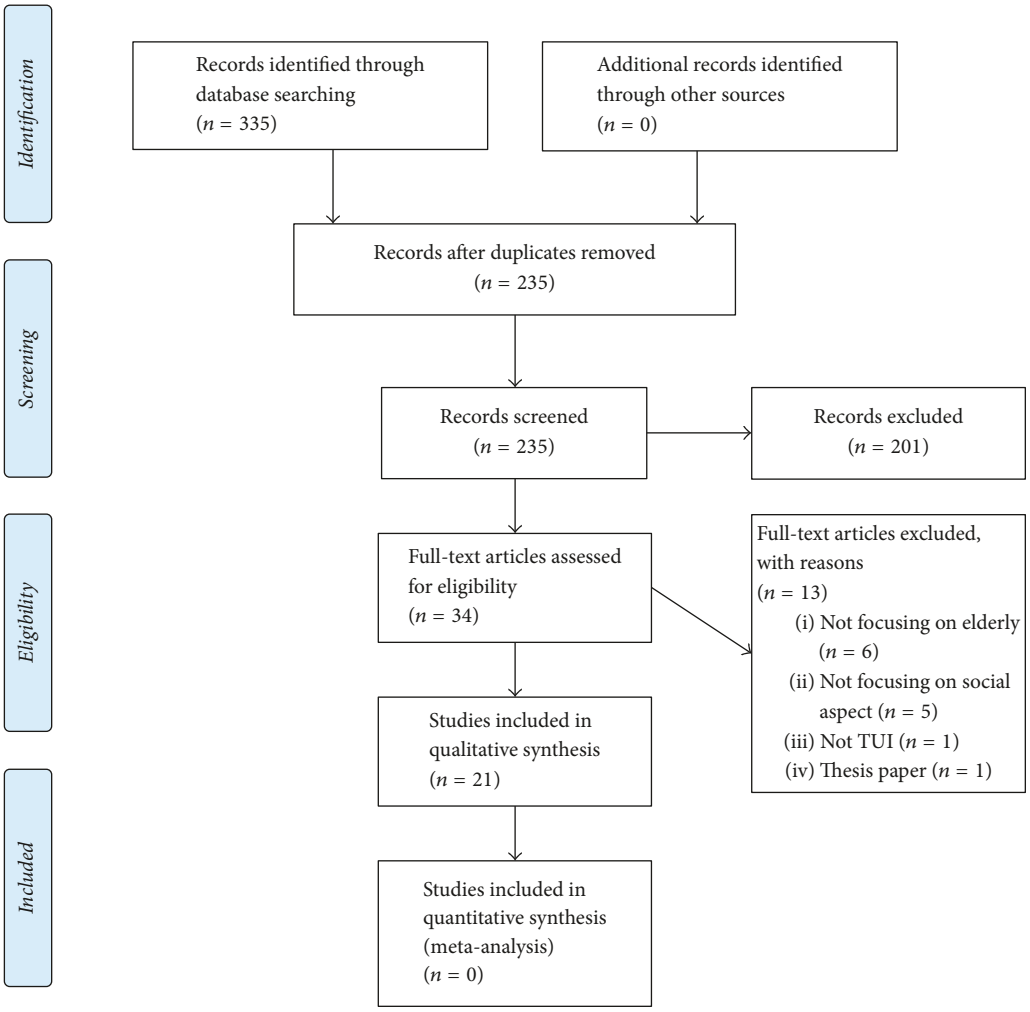

Figure 3: Process of review using a PRISMA flow diagram.

Table 1: Summary of electronic databases and number of search results.

Electronic database	Number of search results
ACM	66
Springer	69
Science Direct	14
Engineering Village	8
IEEE	10
Google Scholar	168
Total	335

We did not exclude mobile, computer, and tablet at this stage because we considered the possibility of researchers using these technologies in developing their TUI prototypes. The results from each electronic database are summarized in Table 1.

Total records identified through database search and other sources from two searches are 335 papers. Records after removing duplicates are 235 papers. After removing duplicates, abstracts of the papers were read, and the content of the papers was screened by both researchers to determine if the papers fulfilled all the inclusion criteria and exclusion criteria.

Synonym terms for "elder" such as aged, old, and senior were searched throughout the papers to check if they fulfilled criteria (1). The papers were also checked to determine if they fulfilled the definition of TUI. A TUI makes no distinction between input and output, just like an abacus [19]. Prototypes that were purely mobile, computer, or tablet-based were also excluded. The screening resulted in 34 papers. 201 papers were excluded at this stage due to the fact that they did not fulfil all of our inclusion and exclusion criteria as stated in Section 3.2.

After screening, the papers were assessed and read in full-text for eligibility, to check if they fulfilled all the inclusion and exclusion criteria. 21 papers were included as relevant papers that use the concept of TUI in enhancing social interactions of elderly people. Figure 3 illustrates the process using a PRISMA flow diagram [42]. There were no studies included in quantitative synthesis due to no common data being measured in the selected papers.

3.3. Studying the Selection and Reporting the Results. The 21 selected papers were studied and reviewed. The research questions guided the review process, and the review was based on the following criteria:

(1) Objective of the study.

(2) Discipline in which the author and coauthors of the papers worked.

(3) Methodology guiding the design and development of the prototype.

(4) Methodology guiding the evaluation processes.

(5) User involvement (user here means elderly people. Involvement means involvement at any stage of the research).

(6) Sample size and demographics (during evaluation).

(7) Evaluation method and data capture.

Most of the papers aimed at designing, developing, and evaluating their prototypes which targeted to address loneliness and social exclusion among elderly people. Most of the authors and coauthors of the papers worked within the technology field, while a few worked in art and design. Regarding methodology for design and development of the prototypes, six papers [43–48] adopted a user-centered approach which involves users in the iterative process of requirement gathering, design, development, and testing. Although other papers did not use user-centered approach, some of them did involve users to identify their requirements. For instance, Zhao et al. [49] conducted interviews with 10 elderly people in their first design study, while Davidoff et al. [50] used semistructured interviews with six email-using elderly participants.

In terms of methodology for evaluating the prototypes, one paper [51] did not present any testing or evaluation of their proposed TUI. The other 20 papers used empirical approach. All 21 papers presented their prototypes and all but two [51, 52] involved users in their evaluations. Four papers [44, 46, 53, 54] reported that they had evaluation but did not present information about their sample. Thus combining the two papers that did not involve users in their evaluation, a total of six papers had no sample. The summary of the review is presented in Table 2.

4. Discussion

4.1. Evidence and Number of Relevant Papers. The review results indicate very little use of TUI to enhance older adults' social interactions. Our search using six electronic databases resulted in 167 search results, and out of these 167 search results, only 21 papers fulfilled all the inclusion and exclusion criteria. The number of papers selected after all screening processes shows the lack of research in using TUI for elderly people's social interactions.

The search results include many research works using touch gestures, such as mobile applications and tablet-based applications since touch gestures are also a kind of "tangible" user interface. However, this review only targets on the TUI that uses Tangible Bits, where digital bits are coupled with everyday physical objects and architectural surfaces [18]. Elderly people do have problems using touch-gesture devices [16, 64, 65]. As a result, researches where the prototype was mobile, tablet, and even computer-based were excluded and we only considered TUI that adopted everyday physical objects in our review.

No time range was applied during the search in order to include as many search results as possible. Although the TUI was introduced by Ishii and Ullmer [18] nearly 20 years ago, our review only managed to identify 21 relevant papers using TUI to improve the social interactions of the older adults. Three out of 21 papers [44, 46, 47] were on same project, kommTui. Thus the number of individual studies was even smaller. The small number of papers indicated little evidence of research work done in this field.

In terms of data capture by the 21 reviewed papers, most of them focused on the usability aspect of the prototype. Only seven papers focused on the social interaction of the elderly people. Foverskov and Binder [43] studied the possibilities for elderly people to have more active interactions and dialogues; workshop series conducted by Ehrenstrasser and Spreicer [47] in 2010 explored on the communication habits of elderly people; Meza-Kubo et al. [56] studied interactions of elderly people within cognitive stimulation sessions and the factors affecting the relationships of them with their family through case study; Huldtgren et al. [58] observed the interactions of the elderly participants with a tangible multimedia book and interactions between people during reminiscence sessions; Marques et al. [53] conducted usability testing to observe how elderly people used tangible objects and interacted with other players while playing tabletop game; using tangible objects and tabletop surface, Murko and Kunze [62] studied the well-being of the dementia patients in terms of social interactions between caregivers and patients; and lastly, Angelini et al. [63] evaluated whether elderly participants managed communicate with the person on the other side of the prototype, a tangible window. The small amount of reviewed papers focusing on social interaction of the elderly people clearly shows the lack of evidence in using TUI to make an impact on the social interactions of older adults.

4.2. The Objectives of the Papers. The majority of the papers in our review focused on usability, accessibility. and user experience, as they effect the elderly people's acceptance of the newly introduced technology. However, some focused more on other aspects. For example, Fu et al. [55] targeted to provide elderly people a tangible self-health management system. In the mean time they acknowledge that health and social interaction are very much related. Thus, the system linked the elderly people with their family, friends, and doctors by cross-media platform and social network.

Meza-Kubo et al. [56] designed a TUI pervasive cognition simulation collaboration system. The system aimed at not only reducing the risks of suffering a cognitive decline related condition, but also addressing the technical, social family networks and illiteracy gaps of the elderly people. Augmented reality cubes were designed by Boletsis and McCallum [57] to

Table 2: Summary of review results.

Paper #	Objective of the paper	Discipline	Design & development methodology	Evaluation methodology	User involvement	Sample size & demographics	Evaluation method & data capture
[50]	To design and conduct a preliminary evaluation of a "the book as user interface"-based email system for elderly people	Human-Computer Interaction	Semistructured interviews with email using elderly participants	Yes. Empirical	Yes	Six participants (five were using a computer for the first time, while one was a complete beginner)	Questionnaire. Perceived ease of use and feelings of independence
[45]	To promote reminiscence and memory sharing activities by explore the suitability of using digital media with tangible scrapbook application	Information Technologies, Computer Science and Informatics	User-centered	Yes. Empirical	Yes	Not elderly participants	User study experiment and questionnaire. Usability in terms of performance results, ease of use, usefulness, and so on
[44]	To better design usable and user-sensitive interaction for the elderly people, with the purpose to increase their acceptance using ICT for communications	Technology Assessment & Design, Inclusive Design and Research	User-centered	Yes. Empirical	Yes	Not mentioned	Workshop. Usability
[49]	To design and evaluate a TUI embedding asynchronous voice message systems to address elderly people's intergenerational communication	Bioengineering, Computer Science and Engineering, Art	Research through study approach with engaging users	Yes. Empirical	Yes	Not elderly participants	Qualitative evaluation. Usability and user engagement
[43]	To study how to create possibilities of interaction and dialogues using tangible social media via the design concept of Super Dots	Centre for Theory & Method/Co-Design	User-centered	Yes. Empirical	Yes	Age was not clearly mentioned. One participant was 82 years old. A total of six elderly participants were mentioned throughout the paper	Workshops. Possibility for interaction and dialogues
[46]	To apply and analyze different multimodality (aural, visual, tactile, gesture, posture, and space) in designing tangible communication systems for elderly, with the purpose to support communication and social interaction among elderly people. Prototypes were implemented and evaluated	Informatics & Design, Inclusive Design and Research	User-centered	Yes. Empirical	Yes	Not mentioned	Workshops with use cases. Observation on how players interacted with the TUI in terms of different modalities

Table 2: Continued.

Paper #	Objective of the paper	Discipline	Design & development methodology	Evaluation methodology	User involvement	Sample size & demographics	Evaluation method & data capture
[55]	To design more accessible and enjoyable chronic disease self-health management system for the elderly people	Information Art & Design, Computer Science and Technology	User research (interview, observation, persona)	Yes. Empirical	Yes	10 participants (only details of seven of them were given). Age ranged from 60 to 90, with different diseases like hypertension, bronchitis, diabetes, and disabilities such as poor memory, visual impairment, motor impairment, and so on	Role-play to access the elderly people's interaction pattern; cord sorting to understand mental model. Visual interface was also tested
[47]	To design accessible, functional and acceptable TUI for elderly people's digital inclusion through user involvement	Informatics & Design, Inclusive Design and Research	User-centered	Yes. Empirical	Yes	Series of workshop were conducted from year 2010 to 2012 but sample size and demographics of the participants were not mentioned	Workshops with interviews, design sessions, focus groups, usability testing, and feedback rounds. Multimodal analysis frames were also used as evaluation tools for redesign process. Workshop series in 2010: focus on the exploration of communication habits of elderly people. Workshop series in 2011: focus on the interaction design. Workshop series in 2012: focus on the usability
[56]	To design and evaluate a TUI pervasive cognition simulation collaborative system, with the aim of addressing technological, social family networks, and illiteracy gaps regardless of physical location for elderly people	Computer Sciences	Case studies (identifying and understanding users, roles, interactions, and identifying factors that affect relationships of elderly people with their family)	Yes. Empirical	Yes	Six healthy elderly participants with one relative each (five adult children, age ranged from 33 to 55 & one grandchildren aged 21)	Observation and questionnaire to study perception of use (ease of use, usefulness, enjoyment, and anxiety) and projected use (intention of use and expected use). Open questions to study communication practices and cognition simulation activities

Table 2: Continued.

Paper #	Objective of the paper	Discipline	Design & development methodology	Evaluation methodology	User involvement	Sample size & demographics	Evaluation method & data capture
[57]	To design a serious game for cognitive training and screening for elderly people by utilising augmented reality and tangible objects	Computer Sciences	Based on design principles, design, and usability suggestion from other studies and collaboration with physician	Yes. Empirical	Yes	Five elderly participants who were 60 years old and above, independently performing activities of daily living, not diagnosed with any kind of dementia, familiar with technology (i.e., using or having used laptop, tablet PC, and smartphone) and video games (i.e., playing or having played video games before) and would be novice augmented reality users	In-Game Experience Questionnaire to evaluate the game experience. System Usability Scale to evaluate the usability and interaction. Open, semistructured interviews to study participants' personal playing experience
[58]	To employ tangible multimedia artifact to support reminiscence sessions	Media, Design, Innovation Sciences	Field research	Yes. Empirical	Yes	Eight people with dementia (7 women and 1 man. Age above 80) suffered from different levels of Alzheimer's with handicaps such as mobility problems, hearing problems, speech impairments (related to strokes), and tremors; and four caregivers	Sound recording for transcripts and observations to study the interactions with a tangible multimedia book, interactions between people, and physical reactions of participants during reminiscence sessions. Focus group to get feedback from caregivers about the reminiscence sessions

Table 2: Continued.

Paper #	Objective of the paper	Discipline	Design & development methodology	Evaluation methodology	User involvement	Sample size & demographics	Evaluation method & data capture
[59]	To design an immersive interface focusing on edutainment contents, with the aim for elderly people to enjoy themselves and improve their health and quality of lives	Internet & Multimedia Engineering, Advanced Fusion Technology, Game Engineering,	Not mentioned	Yes. Empirical	Yes	Experiment 1: 30 people (five age groups (20, 30, 40, 50, and 60) and each age group consists of three men and three women). Experiment 2: 8 subjects (three women & five men. Age ranged from 50 to 70)	Experiment 1: performances of playing the games were evaluated to measure the effects of familiarity to the interaction metaphor. Learning curves of the digitalized game were tested to measure the effects of familiar interaction metaphor. Experiment 2: time required to complete each game was measured to see the effects of believable interaction metaphor. Subjects were interviewed with questionnaire to measure user satisfaction
[48]	To develop a tangible intergenerational collaborative game for elderly people	Embedded Interaction, Informatics	User-centered	Yes. Empirical	Yes	Two elderly women (age ranged from 56 to 65) who did not have grandchildren and described themselves as advanced computer users, and one boy (age 8) who played computer games frequently	Observations and comments from the participants. The acceptance, the handling with the game and suggestions to improve the games and to adapt the players' requirements
[52]	To bridge intergenerational gap between elderly and young people with the aim of engaging elderly people in social media through photos and solving social isolation barrier	Imaging Media	Not mentioned	Yes. Empirical	No	N/A	Comparing with other existing systems (Sound Shot, AudioBoom, and Yappie) and the previous work (audio enhanced paper photos) in terms of functionality and performance of system
[60]	To design and evaluate a tabletop game especially created for senior citizens, with the aim of providing leisure and fun	Industrial Design, Communication and Information Sciences	Field study (observation, interview)	Yes. Empirical	Yes	Eight elderly participants (three women & five men. Age ranged from 65 to 73)	Questionnaire and interview. Game experience of the elderly players

Table 2: Continued.

Paper #	Objective of the paper	Discipline	Design & development methodology	Evaluation methodology	User involvement	Sample size & demographics	Evaluation method & data capture
[61]	To design a tabletop solution that provides a pleasant social cognitive training, with the aim of preserving cognitive functions in elderly people	General Psychology, Bioengineering and Technology	A series of stages including identification of requirements, planning and development of initial concepts, and usability and acceptance analysis	Yes. Empirical	Yes	Usability evaluation: three different groups of four elderly players (age ranged from 64 to 75, mean age 68.083, standard deviation 3.34); trial managers and usability experts. Level of acceptance of the prototype: 107 elderly users in three trial centers (Spain 46%, England 14%, and Norway 40%) and a group of 21 experienced users. Consistency of the monitoring module: 59 elderly players	Usability evaluation: video-analysis and observation for elderly players to identify requests for help. Checklists for trial managers and usability experts to test usability. Level of acceptance of the prototype: questionnaires and focus groups to evaluate acceptance. Consistency of the monitoring module: statistic comparison of the scores by Eldergames with those obtained with the Wechsler Abbreviated Scale of Intelligence to validate the scoring system
[54]	To study the guidelines for making users feel playful and engaged while playing game by developing an application	Computer Sciences	Based on guidelines	Yes. Empirical	Yes	Not mentioned	Observation and comments from participants. The impact of games in terms of user experience
[51]	To present a multitouch social interaction system for elderly people that enables them to engage the benefits of ICT and enhance their social interaction	Industrial Design, Computer Science and Information Engineering	Not mentioned	No	No	N/A	N/A
[53]	To improve the quality of elderly people's life by providing a better and richer gaming experience with the use of real objects while interacting with digital games	Computer Engineering	Not mentioned	Yes. Empirical	Yes	Not mentioned	Observation during usability testing. The use of tangible objects and the interactions of elderly people with them while playing the game

Table 2: Continued.

Paper #	Objective of the paper	Discipline	Design & development methodology	Evaluation methodology	User involvement	Sample size & demographics	Evaluation method & data capture
[62]	To explore the use of surface computing and TUI for people with dementia by developing three prototypes	Human and Technology Interaction	Interviews and workshop with experts, use of personas and referencing books and material collections for occupational therapy in dementia	Yes. Empirical	Yes	14 participants (nine women & five men. Age ranged from 77 to 93) representing all degrees of dementia	Observation, system log, and interview with occupational therapists. User experience and system usability, well-being of the dementia patients in terms of social interactions between caregivers and patients
[63]	To design a system where the technology is hidden behind a well-known metaphor so that system accessibility and user acceptance of elderly people can be improved	Technology for Human Well-being, Hospital & Health Care, Technology	Based on guidelines, feedback from lab users and visitors	Yes. Empirical	Yes	Eight participants (five women & three men. Age ranged from 69 to 100) with different health conditions. Had primary education level and rarely used new ICT. Social interactions varied from weekly visit to yearly visit and from receiving calls from family and friends to no calls	Observation to study task-based analysis (communication task, recognition task, and opening/closing task) and interaction analysis (proximity in terms of distance where people stand from each other while interacting, participants' gestures and actions, and emotions). Semistructured interview to study user experience

use in games for cognitive training and screening for elderly people. They also emphasized the social interaction aspect while studying the game mechanics.

4.3. Study Design and Involvement of Elderly Users. Due to cultural differences, we did not specify the older adults' age since the definition may vary from country to country. Out of the 21 papers, 19 involved elderly user involvement throughout their research while two papers [51, 52] did not mention anything about involving elderly participants.

The study design of these 21 papers did not give enough detail in terms of the elderly user involvement. Spreicer et al. [44], Tellioğlu et al. [46], Marques et al. [53], and De la Guía et al. [54] did not provide much information about their participants throughout the paper. This made it difficult for us to understand more about their study design.

Although Zhao et al. [49] interviewed six women and four men whose ages ranged from 70 to 86 for their design study, they did not include them in testing. Instead, they only had a qualitative evaluation where they involved around 200 people that visited their exhibition and seven instructors from universities. These evaluation results would be able to tell us more about the impact of using TUI in enhancing social interactions of the older adults if the evaluations had been done by their target users, the elderly people. West et al. [45] did the same thing. 14 elderly participants whose ages ranged from 63 to 81 were involved in their design process. However, seven users whose ages ranged from 20 to 40 were asked to evaluate the prototype.

Nevertheless, six out of 21 papers [43–48] used a user-centered approach. These studies showed that involving the elderly users at an early stage, such as gathering input, could determine more specific and precise user requirements while designing the prototype. Elderly people tend to need more time to learn how to use new technology. Thus, taking into the older adults' needs into consideration is vital while designing new technology for them [16, 66].

Another finding is that West et al. [45] and Ehrenstrasser and Spreicer [47] utilised cultural probes to provoke inspiring responses from the elderly participants; they came out with a design that suited the end users. Cultural probes can result in a design process which is more responsive, and they are suitable to be used when target users are unfamiliar [67].

4.4. The Disciplines Where Researchers Worked. In terms of disciplines where the papers' writers and cowriters worked, the review shows that the idea of adopting TUI in improving social interactions of elderly people has not been widely explored in academic disciplines. There were some collaborations between technology and art, but very little with other related disciplines such as health sciences and social sciences. Only three papers [49, 61, 63] demonstrated multidisciplinary collaborations. Collaborations between technology and other disciplines such as health sciences and social sciences might tell us more about the benefits of using TUI to enhance social interactions of elderly people.

5. Recommendations

5.1. Precise Use of the Term "Tangible User Interface". Ishii and Ullmer [18] define TUI as a user interface that augments the real physical world by coupling digital information to everyday physical objects. Not all tangible objects are everyday physical objects. Thus, there is definitely a difference between a user interface that is tangible and tangible user interface. Many researchers quote works which use touch devices such as tablets and smartphones as TUI. However, these devices are not everyday physical objects.

5.2. Elderly Users' Involvement throughout the Whole Research Process. Out of 21 papers in our review, Spreicer et al. [44] Tellioğlu et al. [46], Marques et al. [53], and De la Guía et al. [54] did not provide clear information about their elderly participants, while West et al. [45] and Zhao et al. [49] only involved elderly participants during their design process and not in the testing or evaluation process. Having elderly participants before or during design can ensure more precise user requirements from the actual users: elderly people. Without having them test the prototype, it cannot lead researchers to a more accurate evaluation and validation of the prototype. As a result, we see the importance of involving older adults through the whole research study, from designing the new technology for them to having them test the new technology.

5.3. More Research on Using TUI to Enhance Elderly People's Social Interactions. From this review, we can see that TUI has indeed been adopted to enhance elderly people's social interactions, but only to a minimal extent. The review resulted in 235 relevant papers after eliminating the duplicate ones, and then only 21 papers were selected after all the screening with full-text reading. Out of these 21 papers, three papers [44, 46, 47] presented the same prototype, kommTui. Given that TUI was introduced 20 years ago, our findings with only 21 papers indicate the limited amount of research studies in this field. During our review process, we came across a few papers which only focused on aspects such as learning and training. These papers are not included in our review.

5.4. More Focus on the Social Interaction Aspect in addition to Usability during Evaluation. During the evaluations, usability aspects were studied in most of the papers, and in their evaluation, social aspects were completely neglected. Out of the 21 papers, only seven papers [43, 47, 53, 56, 58, 62, 63] focused on the social interaction aspect during their evaluation. Other papers like Davidoff et al. [50], West et al. [45], Spreicer et al. [44], and Zhao et al. [49] focused on usability aspects, such as ease of use, performance results in using the prototype, and feelings of independence. Because there were so few papers, we decided to include them nevertheless. As a result, we did not define quality criteria, and only presented the works they had done. While introducing a new technology for older adults to improve their social interactions, it is important to evaluate the impact of their social interactions and not just the usability of the prototype. A prototype that scores high

in the usability aspect might turn out to be not useful to the target users, thus not improving their social interactions.

5.5. Interdisciplinary Collaboration. As shown in Section 4.4, there was very little collaboration in terms of disciplines. There is a definite strong relationship between health and social well-being in the elderly population. By using easy, accessible technology tools, the elderly people can benefit from having a more active social life, which leads to better health too. Only three papers [49, 61, 63] showed collaborations with other disciplines. While most of the papers did not emphasize the relationship between technology, health, and social aspects, we would like to highlight the importance of interdisciplinary collaboration, and hopefully, more research studies can be carried out together by researchers with different yet related backgrounds.

5.6. Longitudinal Study on Impact in a Larger Scale. The impact of using TUI to enhance social interactions in older adults is significant; it can be even greater if interdisciplinary research study can be conducted over a more extended period to see its impact from a health perspective, such as the quality of life and health of older adults. A longitudinal study can be conducted. This will be a more precise measure since it can serve as a follow-up after introducing the prototype to older adults. All in all, we hope to see our literature review inspire more research work in this field. This research work can be extended to more collaboration with researchers from other countries. It is certainly worthwhile to see how TUI can improve the social interactions of older adults in both a longer period and a larger geographical picture.

5.7. Guidelines for Developing and Evaluating TUI for Older Adults. Lastly, while we have guidelines for developing and evaluating mobile application such as The World Wide Web Consortium (W3C) Web Accessibility Initiative's (WAI's) accessibility guidelines, we do not have a set of guidelines specifically created for TUI. Needless to say, we do not have the guidelines to design and evaluate a TUI that are targeted for older adults. These guidelines which can be used both in developing and in evaluating can help researchers, designers, and developers to provide TUI that is accessible, usable, and easy to learn and use and keep the elderly users motivated while using it. Lack of guidelines can result in a system that is neither accessible nor useful to users. Some existing guidelines for mobile applications and technology targeted to elderly people could be applicable. However, further study has to be conducted to verify this.

6. Conclusion

With the fast growth of ageing population, lack of social interaction among elderly people is becoming an increasing social and economic challenge in many countries. The objective of our systematic literature review is to gain an overview of the state of the art research and evident effects of TUI as an intervention on social interactions of older adults. This research is therefore timely and important both to the research communities related to elderly, health, and TUI but also have implications for the society.

At the early stage of the review we found out that many researchers referred to their touch screen, mobile-based, and computer-based prototypes as a "tangible" user interface. By adopting the definition of TUI by Ishii and Ullmer [18], we managed to make a clear distinction between user interface that is tangible and tangible user interface. Doing so helped us develop the exclusion criteria used in our search and screening process.

We acknowledge that the quality of the research in the reviewed papers varies. Data captured by the 21 relevant papers were very different, and there were no criteria in common where we could evaluate these papers. All of them focused on very different aspects and thus, it was impossible to come out with a quality score. As a result, we could only present what has been done, and where there is a gap.

Although the papers aimed at designing, developing, and evaluating prototypes to address the loneliness and social exclusion among elderly people, most papers only evaluated the usability aspect of the prototype. Collaborations between technology and other disciplines such as health and psychology have been low among the researchers. There is a lack of user involvement, both in designing TUI for the elderly people and in testing and evaluating the prototype.

The process of this systematic literature review has been fruitful. Referring to the guidance by Keele [39] and referencing other published literature reviews, we have conducted this literature review to address our research questions. The literature review resulted in 21 papers that fulfil all the inclusion and exclusion criteria. As three out of these 21 papers presented the same prototype, this makes the amount of prototypes even fewer. The results from the literature review clearly indicate very little use of TUI in making an impact in elderly people's social interactions, especially since TUI was introduced by Ishii and Ullmer [18] 20 years ago.

We acknowledge that research conducted in different countries defines the age group differently. Some research might have also adopted TUI but did not use the exact term, so they did not appear in our search results. Thus, we might have overlooked some papers. All in all, by conducting this literature review, we hope that more researchers can be inspired to develop and evaluate TUI for enhancing elderly people's social interactions. Our future work will focus on designing and evaluating a TUI system for social interaction among elderly people. We will adopt a user-centered approach. By including the elderly people throughout our design, development and testing iterations, and collaborating with researcher from health sciences, we hope to gain more evidence on how TUI can contribute to enhancing the social interactions among elderly people and consequently improve their general well-being.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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Tangible Cup for Elderly Social Interaction: Design TUI for & with Elderly

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Abstract

Social interaction is found to have significant impacts in our quality of life. Information and communications technology (ICT) has been designed to improve our social interaction and well-being. Elderly people face challenges in learning and using ICT due to their age-related limitations and that they are non-digital natives. Their needs are not sufficiently addressed in ICT systems. Tangible user interface (TUI) which couples digital information to everyday physical object is considered to be more intuitive and suitable for elderly people. TUI has been adopted in some studies in order to improve quality of life in the elderly, but very few focus on the social aspect. Thus, this research aims to develop a TUI to improve elderly social interaction and well-being. We have adopted user-centered design and co-design approach in designing the Tangible Cup. Through the design process, we generated a list of lessons learned which can serve as a guide for what to consider when designing TUI for elderly people and when involving elderly people in the design process.

Keywords

Tangible user interface; elderly; social interaction

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Introduction

People nowadays tend to live longer. Social participation is an important factor in elderly people's health and well-being (Gilmour 28). Studies have shown that loneliness is associated with heart disease, hypertension, stroke and lung disease (Petitte et al. 113). Thus, in order to remain healthy, elderly people must remain socially active. ICT has been designed to improve our social interactions and well-being. However, due to their age-related limitations and that they are non-digital natives, elderly people currently find ICT difficult to learn and use (Chou et al. 928). They face many challenges when it comes to learning and using ICT, and their needs are not always sufficiently addressed in ICT systems.

TUI couples digital information with everyday physical objects, and is thus considered to be more intuitive and suitable for elderly people (Spreicer 313). TUI has been adopted in some studies in improving quality of life in the elderly, but very few focus on the social aspect (Bong et al.). Issues such as lack of elderly user involvement throughout the research process, and lack of guidelines for developing and evaluating TUI for elderly people, have been identified. These issues can result in TUI that is developed for elderly people not being as intuitive and suitable as it should be. We aim to address these issues by providing a list of lessons learned from our design process for Tangible Cup.

By using user-centered design and co-design approach, we have involved elderly participants in our design and evaluation processes. The end product of this research, Tangible Cup, is expected to be a more intuitive and user-friendly ICT tool for elderly people, which can encourage their social interaction with others. Through designing Tangible Cup, we have developed a list of lessons learned in connection with designing TUI for and with elderly people.

Discussion

The Prototype: Tangible Cup

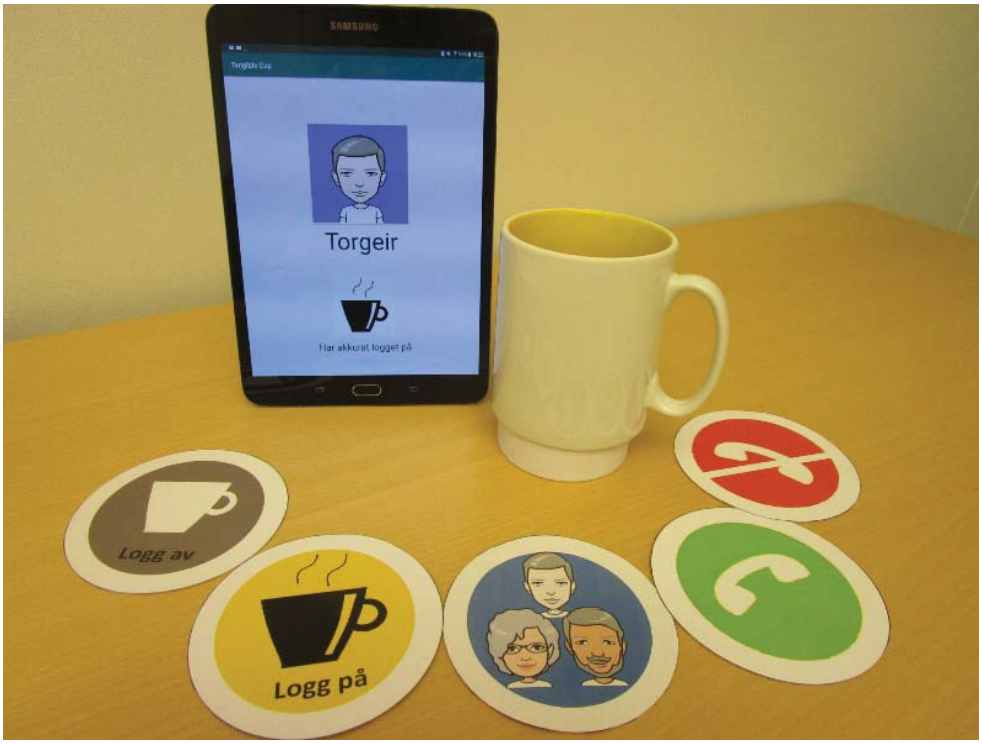

Fig.1. Tangible Cup.

Tangible Cup consists of four components: a cup, a cup attachment (under the cup), five cup coasters and a tablet (Fig.1). Users must first attach the cup attachment to the bottom of their own cup. After that they can perform desired actions by moving their cup (with the cup attachment already attached) and placing it on the various cup coasters. The cup attachment contains an RFID reader which reads the RFID tags on the cup coasters. The five coasters are assigned the following functions: *log in, log out, start call, end call* and *search contacts*. An app installed in the tablet enables the users to call other users who are online.

To start using Tangible Cup, users need to go online by placing their cup on the *log in* coaster. Once they are online, they can place their cup on the *start call* coaster whenever they want to call someone or to accept an incoming call. In order to end or reject a call, they have to

place the cup on the *end call* coaster. The *search contacts* coaster is used for finding other Tangible Cup users who are online at the same time. Finally, to log out they should place the cup on the *log out* coaster.

Methods and Results

We adopted user-centered design and co-design approach. First, a focus group interview was conducted with three elderly participants and a volunteer to gather the initial requirements for Tangible Cup. The prototype was developed based on these requirements. Four iterations of design, implementation and usability testing were then carried out. Usability testing was conducted with two elderly participants at the end of every iteration. During the testing, the participants were asked to perform a series of tasks using the prototype while being observed. After that, they were asked about the design of the prototype and their experiences of using it. The comments and feedback from the usability testing were incorporated into the next iteration to improve the design. In addition, new features were implemented into the existing design.

The co-design approach was applied throughout the whole research process, from focus group interviews to usability testing of all iterations. This was done to ensure that the prototype was designed and developed with the perspectives and needs of our target group, the elderly, in mind (Steen et al.). All the participants (P1 to P10) were briefed and asked to give their consent prior to participating in the study. Information about the participants is summarized in Table 1.

Table 1. Information about Participants

ID#	Age	Gender	Work Experience	Years of Education	Participation
P1	76	M	Management	14	Focus group
P2	71	M	Computer engineer	20	Focus group
P3	71	F	Administrative	16	Focus group

ID#	Age	Gender	Work Experience	Years of Education	Participation
P4	17	F	Currently at upper secondary school. Volunteer in elderly home care services	12	Focus group
P5	74	M	Diver	12	Usability testing iteration 1
P6	74	F	Secretary	14	Usability testing iteration 1, 2, 4
P7	70	F	Finance	15	Usability testing iteration 2
P8	77	M	Truck driver	8	Usability testing iteration 3
P9	77	F	Housewife and catering	8	Usability testing iteration 3
P10	81	M	Academia	19	Usability testing iteration 4

The focus group interview was conducted at a senior center where iPad courses and walk-in sessions on ICT assistance were held. First, questions were asked about elderly people's use of ICT and their social lives. They were then presented with the idea of Tangible Cup, together with three real cups of different sizes (a big mug, a medium-sized coffee cup and a small expresso cup). The participants were given blank sheets of paper and were asked to draw their own design for Tangible Cup (Figure 2). While they were drawing, they talked among themselves and made changes to their designs.

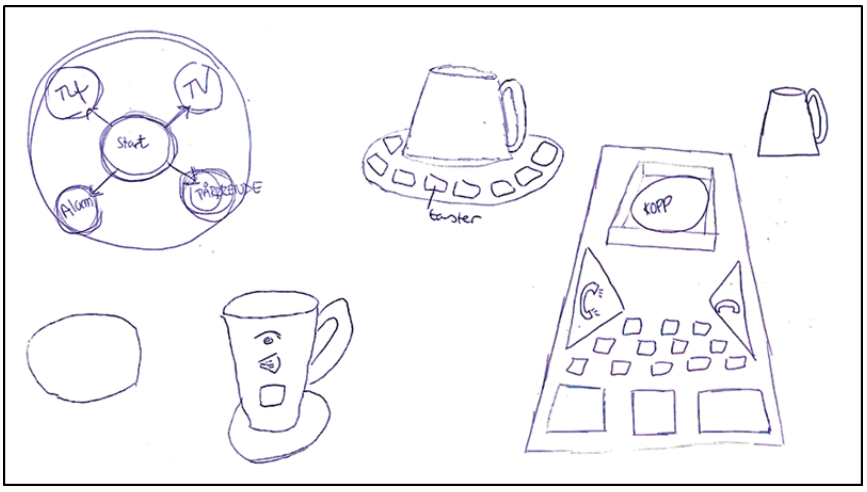

Fig. 2. Drawings of Designs for Tangible Cup Made by the Focus Group Interview Participants.

The following considerations were gathered from the focus group interview. The participants preferred a typical medium-sized coffee cup because it mostly closely represented Norwegian coffee-drinking culture. The cup had to be light and have a big, strong handle which the users could easily hold with their fingers to lift it. They coupled Tangible Cup with a saucer installed with buttons (Figure 2) to avoid having too many buttons on the cup itself. The elderly tend to have difficulties with small buttons and 'confined' user interfaces for interaction. In terms of functionality, they all agreed it should be kept to a minimum and that the interface should not have too many options. Finally, it should be dishwasher-proof, and the interface for interaction should be waterproof to protect it from spills.

Fig. 3. First Iteration Prototype of Tangible Cup.

Based on input from the focus group interview, the first iteration produced a low-fidelity prototype using a table mat and a cup (Figure 3). The participants were given the tasks of making calls and receiving calls, and having conversations. A few usability issues were observed during

usability testing and pointed out during the interview, such as the table mat being too big to carry around, and too many names being displayed on the table mat.

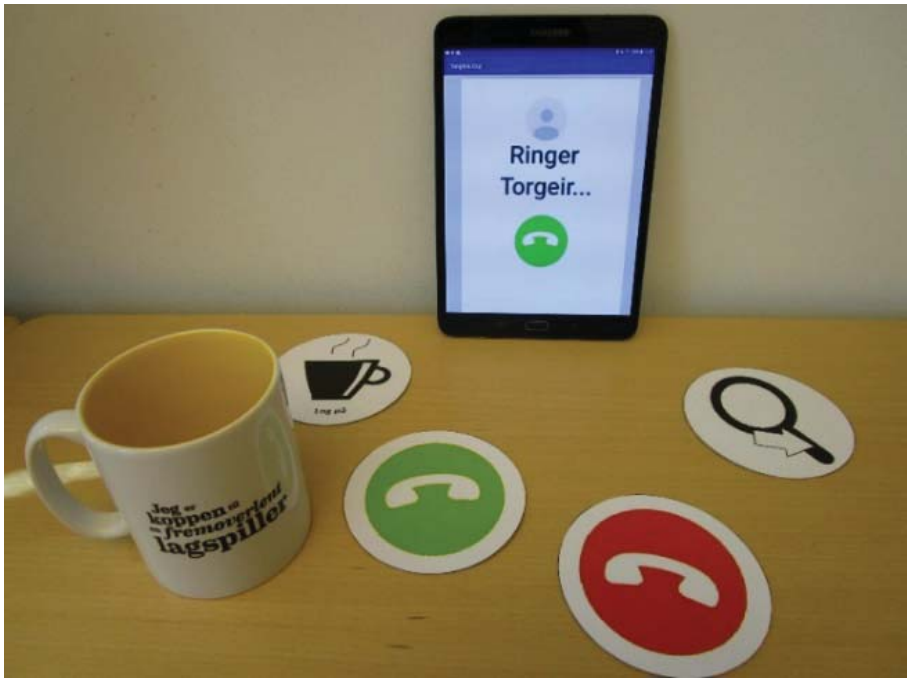

Fig. 4. Second Iteration Prototype of Tangible Cup.

In the second iteration, cup coasters replaced the table mat because they are easier to carry around. Four cup coasters (as shown in Figure 4 from left to right): *log in, start call, end call,* and *search contacts*, were designed to use to interact between the cup and a calling app in the tablet. The test tasks included logging in, recognizing someone who has just logged in, ringing that person, ending the conversation, receiving a call from another person and finding others who were logged in at the same time. The 'Wizard of Oz' technique (Kelley 33) was adopted in the testing.

A few usability issues and recommendations were gathered. The symbol on the *search contacts* coaster was found confusing. P6 suggested using a symbol showing multiple blank avatars instead. Confusion occurred when an upcoming action required users to use the same coaster as for the previous action. For example, when the cup was used to end a conversation by

placing it on the *end call* coaster, confusion would arise if someone called and the recipient wanted to reject the call using the same *end call* coaster. In addition, P6 found the ringing sound too sharp. She suggested that a favorite melody could replace the sharp ringing sound. Finally, there was no *log out* coaster.

Fig. 5. Design of Coasters in the Third Iteration. Left to right: *log out*, *end call*, *start call*, *log in* and *search contacts*.

In the third iteration, we modified the design of the coasters (Figure 5). We included log out from using Tangible Cup in test task in this iteration. The usability testing revealed two similar issues from the previous iteration. First, confusion when the upcoming action required users to use the same coaster as for the previous action. Second, the challenge of understanding the *search contacts* coaster (Figure 5). P9 did not understand the avatar icon, so she did not understand what the symbol with three avatars denoted. P8 and P9 agreed that it would make more sense if the avatars were made more human-like and given different colors.

During the interview, the users were also asked to co-design the cup attachment. The purpose of the cup attachment is to enable ordinary cups to function as Tangible Cups when the cup attachment is attached to them. They suggested that the cup attachment be designed to resemble a round fridge magnet so that it could be easily attached to the bottom of the cup, in the same way as a fridge magnet is attached to a fridge door.

In the final iteration, we added the cup attachment and modified the design of the *search contacts* coaster to show three human-like avatars (Figure1). In the user testing P6 and P10 were first explained about the cup attachment and how it could be attached to the cup. They were then asked to perform the same test tasks as in the third iteration. P6 and P10 found all the tasks easy to perform. They understood the design of the cup attachment and coasters, and thought that the idea of using Tangible Cup to communicate with the calling app on the tablet was good.

Lessons Learned

Based on our experiences from the design process, we gathered an initial list of lessons learned. These lessons learned can serve as a guide for two purposes: i.e. what should be considered when designing TUI for elderly people and when involving elderly people in the design process. They are not limited to designing TUI for social interaction, and can be used for designing TUIs for elderly people in general. Lesson learned for involving elderly participants can also be applied when designing other digital and ICT tools for this user group.

When designing TUI for elderly people

1. ***Familiar physical objects.*** Elderly participants drew on their own personal experiences and those of others they had observed. The focus group participants told us that they wanted a typical coffee cup that they were used to: medium in size, and with a good handle. In the third round of usability testing, the design of the cup attachment was inspired by items commonly found in the kitchen. Such familiarity would increase user acceptance of the new technology (Spreicer 313).
2. ***Integration of TUI into daily life.*** Wallbaum et al. identified integration of new tangible objects in one's environment as a challenge. To address this, we kept in mind how the TUI object was to be used daily by the users. Tangible Cup was originally

coupled with a table mat, but elderly people do not use their cup in just one place, and the table mat was too big to carry around. The idea of cup coasters was adopted to address this issue.

3. ***Minimal functionality.*** The elderly users prefer few but useful functionalities. Tangible Cup offers no functionality other than that of talking to others. Reducing the complexity of the interfaces may increase elderly people's interest and confidence in learning and using new technology (Bong and Chen 32; Fischer et al. 629; Ijsselsteijn et al. 20).
4. ***Avoid crowded interfaces.*** The elderly users prefer a simpler interface (Ijsselsteijn et al. 20). The interface of Tangible Cup was expanded from just one cup to a cup coupled with five coasters and a cup attachment. This expanded design is less crowded and elderly users will find it easier to use and learn and be less likely to make mistakes.
5. ***Consider elderly people's physical abilities.*** Reduced physical ability has to be considered in gesture-based applications for elderly people (Chen 190), and the same applies to TUI. The focus group interview participants informed us about their preference when it comes to the weight of TUI objects. Elderly users may have reduced arm strength. The weight consideration was also applied in the design of the cup attachment.
6. ***Provide necessary instructions.*** Instructions are essential to ensure that elderly users know what to do should they become confused. The aim of the instructions is error prevention and recovery (Nielsen). When users are not lifting their cup and placing it

on coasters to perform desired actions, the tablet will display instructions on what to do.

7. ***Practicality.*** For our Tangible Cup, it is important that the coasters are waterproof, in case of spills when using the cup. The cup attachment was added to the design of Tangible Cup so that the RFID reader does not have to be integrated into the cup itself. Any cup can be used as a Tangible Cup as long as the cup attachment is attached to it.

When involving elderly people in the process of designing TUI

1. ***Use of actual objects to demonstrate.*** The participants were first briefed about the project. However, it was difficult for them to understand the idea of Tangible Cup. When an actual (though not yet functional) cup was presented, the participants seemed to gain a better understanding of the idea. Without an actual object, it was difficult for the participants to imagine the Tangible Cup.
2. ***Choice of words.*** Elderly people have very different levels of ICT knowledge and skills. Thus, words such as '*log in*' and '*log out*' may be familiar to one person but totally unfamiliar to another. In such situations, it is better to explain in ways that elderly participants with lower levels of ICT literacy can understand (Pieri and Diamantinir 2424). In our communication we have explained them as 'be online' and 'be offline'.
3. ***Find the most natural setting.*** The focus group interview was conducted at a senior center, while usability testing was conducted in the participants' homes. We noticed that the participants felt more comfortable and natural at home. Their ideas and comments were linked to their surroundings. For instance, the idea of a fridge magnet

was proposed after P8 and P9 looked around the kitchen. The issue of the table mat being difficult to carry around was identified by P5 because he wanted to move from his kitchen to his living room to watch television. Their behavior and habits in natural setting must be considered when developing new technology (Intille et al. 165).

4. ***Motivation and encouragement.*** Keeping elderly people motivated and encouraged can build their confidence in using new ICT and thus increase their acceptance of new technology. We noticed that the participants were skeptical towards new technology. To motivate and encourage them, it is crucial to show them that their opinions are being heard and to encourage them to relate to their own experiences.
5. ***Consider the diversity of elderly people.*** Throughout our research, we tried to include elderly participants from different educational and cultural backgrounds, of different ages and with different knowledge levels in using ICT. It is essential to ensure that the diverse characteristics of the elderly people could be addressed.
6. ***Involve elderly users as early as possible.*** We involved elderly participants from the focus group interview, low-fidelity prototype to our final product. The design changed from iteration to iteration based on the co-design and usability testing feedback. Early involvement of elderly users can ensure that the end product properly addresses their needs and at the same time is easy and intuitive for them (Rodeschini 525).

Conclusions

This paper demonstrates a design process for a TUI for and with elderly participants using user-centered design and a co-design approach. Elderly people constitute a diverse user group. Thus, we included participants with varied levels of experience in digital technology.

There are existing guidelines for designing for elderly people such as universal design principles and usability guidelines. However, these guidelines are not sufficient for designing TUI for the elderly. Through our experience with the process of a focus group interview, iterations of the design, and evaluations of the prototypes with the elderly participants, we provide a set of considerations for designing TUI for and with elderly people, which can also be applicable for designing other ICT tools.

We are currently planning a longitudinal study to validate the impact of Tangible Cup in terms of social interaction and quality of life for elderly users. We have yet to include some feedback from our usability testing participants in the current version of Tangible Cup, such as supporting the app as a stand-alone app without the use of Tangible Cup, and personalization. All in all, we hope that Tangible Cup will encourage elderly people to be socially active, particularly those who are not experienced in or who are skeptical towards new digital tools. The lessons learned generated can also help address the special needs of elderly people when it comes to introducing and designing new digital tools for them.

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Article

Technology Acceptance and Quality of Life among Older People Using a TUI Application

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Abstract: Good quality of life is important for healthy ageing. Studies have shown that although information and communication technology can improve older people's quality of life, their technology acceptance level is rather low. Tangible user interfaces (TUIs) enable people to interact with the digital world through everyday physical objects, thus offering more intuitive digital environments for older people. In this study, we employ a TUI prototype to investigate the relationship between older people's technology acceptance and quality of life, the changes in these outcome measures after using TUI, and the associations between them. The TUI prototype, Tangible Cup was used by 20 older participants over a period of three months. Data were collected using the technology acceptance model (TAM) questionnaire, the older people's quality of life (OPQOL) questionnaire and semi-structured interviews. The results showed some positive changes in technology acceptance after the use of Tangible Cup. However, no change in the quality of life was found. While statistically significant correlations between the change in technology acceptance and the change in quality of life were observed, limitations such as small sample size and participants not accurately representing the target population should be noted. Thus, further research is needed to better understand the associations between the change in technology acceptance and the change in quality of life.

Keywords: older people; tangible user interface; technology acceptance model; quality of life

1. Introduction

Quality of life is reportedly strongly associated with health in older people. A cohort study by Iwasa et al. [1] and meta-analyses [2] have reported that people who find their lives worth living have a lower risk of mortality and cardiovascular diseases compared to those who do not. According to the World Health Organization (WHO), quality of life refers to individuals' perceptions of their position in life in the context of the culture and value systems in which they live, and in relation to their goals, expectations, standards, and concerns [3]. Bowling [4] and Bowling et al. [5] stated that there is international interest in enhancing and measuring the quality of life in older age partly because of the increasing number of older people and higher expectations of life within the society. Quality of life is a useful concept in this context; one that shifts our perspective from a narrow medical definition of health to one encompassing the broader aspects of well-being recognized by older people themselves [6].

Studies have shown that the use of information and communication technologies (ICT) could contribute to improving older people's well-being and quality of life [7–10]. Assistive technology in older people's care, such as video-monitoring, remote health monitoring, fall detectors, pressure mats and other electronic sensors and equipment were identified by Miskelly [11] as having the potential to make an important contribution to the care of older people as long as they fit the person's needs and

lifestyle. However, the older people who could benefit most from using digital technology are not usually the ones using it [12].

Because of the difficulties in learning and using ICT, and the belief that ICT is not necessary in their daily life, older people have low acceptance and use. As previous research on technology acceptance has highlighted, many technological interventions could be perceived as a waste of time and money because people do not fully accept and use the technology [13]. Several studies have been conducted to improve the older people's acceptance and use of ICT [8,14–16]. Fischer et al. [17] identified barriers faced by the older people in accepting and using health information technology and they highlighted the importance of designing new technology with the needs of older people in mind. Neves and Amaro [18] studied the use and perception of ICT among older people in Lisbon, Portugal, and found that the lack of functional literacy in ICT was their main reason not to use a computer or the Internet. Chou et al. [19] have studied technology acceptance and quality of life among older people in a telecare programme in Taiwan. They found a strong association between these two outcome measures. Older people who used the telecare programme frequently had better social welfare status, and they scored higher in their technology acceptance and quality of life.

Tangible user interface (TUI) is a form of user interface that couples digital information with everyday physical objects and architectural surfaces [20]. The aim is to enhance the interaction between humans and digital information. TUI has been developed for older people with the potential to improve their technology acceptance [21,22] and quality of life [23]. Spreicer [22], Davidoff, Bloomberg, Li, Mankoff, and Fussell [21] designed TUI applications for older people to send email or short message service (SMS) to each other. Marques, Nunes, Silva, and Rodrigues [23] aimed to improve the quality of life of older adults by using TUI to provide a better and richer digital game experience. Despite TUI's potential to provide an intuitive interface and better ICT experience for older people, very little research has been conducted on the impact of TUI on older people's technology acceptance and on their quality of life as a whole.

In this study, we aim to investigate the relationship between older people's technology acceptance and quality of life, the changes in these two after using a TUI intervention, and the association between the changes in technology acceptance and the changes in quality of life. We focus on older people living alone at home who may be impacted in terms of their technology acceptance and quality of life after using the TUI intervention. The technology acceptance model (TAM) questionnaire and the older people's quality of life (OPQOL) questionnaire were used to measure their technology acceptance and quality of life. We provided a TUI prototype, Tangible Cup to 20 older participants and asked them to use it for three months.

2. Materials and Methods

2.1. Participants

A total of 20 older people (18 women and 2 men, aged 72–89 years) were recruited. They were recruited through a previous project related to quality of life, nutritional status, physical condition and pain, mental and social function among senior center users. The potential participants were first identified and then contacted to be briefed about this study. Our inclusion criteria were that they lived alone, were over 70 years, and were able to walk independently with or without an assistive device indoors. However, as we had problems recruiting male participants, we decided to recruit one man who was living with his wife.

2.2. Ethical Considerations

Our study was pre-approved and registered by the Norwegian Centre for Research Data (NSD); reference number 253545. Prior to participating in our study, the participants were briefed with written and oral information about the study. After receiving the information, all the participants gave

their informed consent. This included the assurance that they could withdraw their consent without consequences at any time.

2.3. The Prototype—Tangible Cup

Tangible Cup is inspired by the idea of adopting TUI to encourage social interaction among older people [24]. The main function of the Tangible Cup is to connect older users to new potential friends. The users did not know each other when they started using the Tangible Cup and they were supposed to make calls to the other online users listed on an app on a tablet.

We have previously designed and developed Tangible Cup by using a user-centered design [25] and a co-design approach [26]. Four iterations of design, implementation, and usability testing were conducted and two older participants were asked to perform a series of testing tasks in the usability testing.

Figure 1 illustrates the components of a Tangible Cup set, which consists of a cup attachment (under the cup), five cup coasters (from left to right: *log out*, *log in*, *search contacts*, *call* and *end call*), and a tablet. To use Tangible Cup, the users moved and placed the cup attachment on the respective cup coasters to perform the tasks. For instance, placing the cup attachment on the *log in* cup coaster will start the calling app in the tablet and log the user in.

Figure 1. Tangible Cup.

2.4. Instruments

This study adopts a mixed qualitative and quantitative methods approach. The OPQOL questionnaire and TAM questionnaire were used to collect quantitative data while semi-structured interviews were conducted to collect qualitative data.

2.4.1. Technology Acceptance Model (TAM)

To develop our TAM questionnaire, we referred to other existing studies that had used the TAM questionnaire to investigate older people's technology acceptance [27–31], and adapted the questions to reflect the use and acceptance of TUI. From these studies, eight determinants were identified as related to technology acceptance for the use of TUI. The determinants are (a) perceived usefulness, (b) perceived ease of use, (c) perceived enjoyment, (d) intention of use, (e) actual use, (f) compatibility, (g) attitude, and (h) self-efficacy. Likert scales from 1 to 7 (1 is strongly disagree and 7 is strongly agree) were used to evaluate the statements related to participants' use of ICT tools. The questionnaire items are presented in Table 1.

Table 1. Technology acceptance model (TAM) questionnaire.

Dimension	Items	Reference
D1. Perceived usefulness	Q1. By using digital communication tools, I can have better social interactions with my friends. Q2. By using digital communication tools, I can have a better social life. Q3. By using digital communication tools, I can make new friends.	[27–31]
D2. Perceived ease of use	Q4. Interaction with digital communication tools is clear and understandable. Q5. Interaction with digital communication tools does not require a lot of mental effort. Q6. I find digital communication tools easy to use. Q7. I find it easy to learn to use digital communication tools.	[27–31]
D3. Perceived enjoyment	Q8. I find it enjoyable to use digital communications tools. Q9. I find it exciting to use digital communications tools. Q10. I find it pleasant to use digital communications tools. Q11. I find it interesting to use digital communications tools.	[29]
D4. Intention to use	Q12. I would use digital communication tools.	[30,31]
D5. Actual use	Q13. I use digital communication tools very often.	[29]
D6. Compatibility	Q14. Using digital communication tools is compatible with most aspects of my social life. Q15. Using digital communication tools fits my lifestyle. Q16. Using digital communication tools fits well with the way I socialize with others.	[28]
D7. Attitude	Q17. Using digital communication tools is a good idea. Q18. I am positive towards digital communication tools.	[28,30,31]
D8. Self-efficacy	Q19. I feel confident about learning to use digital communication tools. Q20. I feel confident about using digital communication tools. Q21. I have the necessary skills in using digital communication tools.	[29]

2.4.2. Older People's Quality of Life (OPQOL)

The OPQOL questionnaire was developed by Bowling [32] as a new measure of quality of life in older age. Using Likert scales from 1 to 5 (1 is strongly agree and 5 is strongly disagree), it evaluates the quality of life of older adults in eight dimensions, i.e., (a) life overall, (b) health, (c) social relationships and participation, (d) independence, control over life, freedom, (e) home and neighborhood, (f) psychological and emotion well-being, (g) financial circumstances, and (h) leisure and activities. Each dimension has four to six questions. The questionnaire was generated based on older people's responses on the positive aspects that contributed to a good life, and negative aspects that reduce their quality of life. The first question, "Thinking about both the good and bad things that make up your quality of life, how would you rate the quality of your life as a whole," evaluates the respondent's quality of life as a whole from very good (1) to very bad (5). The remaining 35 questions are statements, which respondents answer by selecting alternatives from strongly agree (1) to strongly disagree (5).

We translated the OPQOL questionnaire into Norwegian based on the guidelines developed by Beaton et al. [33]. The original OPQOL questionnaire in English was first translated into Norwegian by two native Norwegians. The translated OPQOL questionnaire was then back translated from Norwegian into English by an English native translator. Lastly, the two Norwegian natives went through the translated OPQOL questionnaire from the English native translator and approved the translation.

2.4.3. Semi-Structured Interview

A semi-structured interview guide was used and follow-up questions were asked to clarify their answers. The aim is to gain deeper insight into their experience of using Tangible Cup and to explore the potential of Tangible Cup. Examples of interview questions were: "Tell me about your experience of using ICT/the Tangible Cup?," "Do you have any problems using the Tangible Cup?," "When/How often do you use the Tangible Cup?," "What do you think of the conversations that you have had?,"

"How do you feel after using the Tangible Cup?," and "Anything positive/negative about the Tangible Cup?" Each interview lasted less than an hour and was conducted at the participant's home with only the interviewer and the participant present.

2.5. Data Collection

We performed the data collection for OPQOL and semi-structured interview three times, i.e., pre-testing, mid-testing, and post-testing, while we performed TAM twice, i.e., pre-testing and post-testing. The overall data collection process is summarized in Figure 2. Informed consent was given prior to participating in the longitudinal study. The participants were given a Tangible Cup set during the first visit to their home. They were given a demonstration of how to use Tangible Cup and asked to use it whenever they liked. They then filled out the OPQOL and TAM questionnaires, and were interviewed.

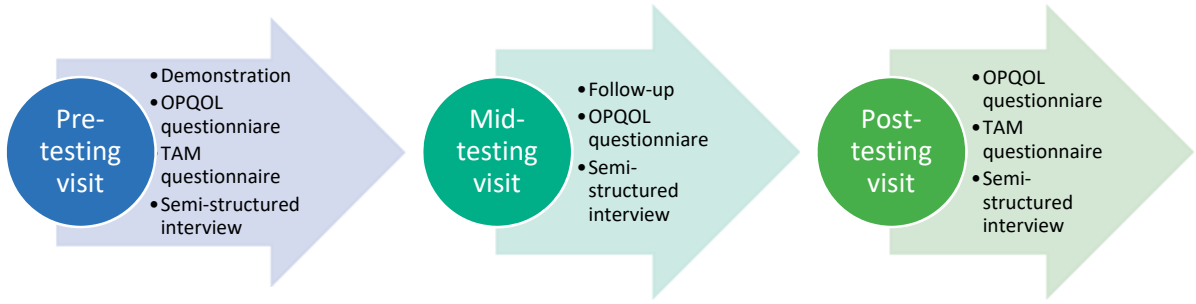

Figure 2. Visualization of data collection process.

After one and a half months, we visited the participants for the second time. Some of the participants had yet to start using their Tangible Cup. Therefore, during the mid-testing visit TAM questionnaire was not filled out and only the OPQOL questionnaire was answered. The participants were then interviewed about their experience of using Tangible Cup.

After another one and a half months, we conducted the post-testing visit. We asked the participants to fill out both the OPQOL and TAM questionnaires, and then conducted a semi-structured interview.

2.6. Data Analysis

The OPQOL and technology acceptance scores, and the changes in these two by dimensions were analyzed. The OPQOL scores are originally 1 to 5 for possible options "strongly agree" and "very good" to "strongly disagree" and "very bad" for 35 statements evaluating the quality of life from different dimensions, and for the first question rating overall quality of life. We transformed and computed all the scores so that the higher scores indicate better quality of life. The scores were summed up by dimensions, i.e., (D1) life overall, (D2) health, (D3) social relationships, and participation, (D4) independence, control over life, freedom, (D5) home and neighborhood, (D6) psychological and emotion well-being, (D7) financial circumstances, and (D8) leisure and activities.

In the TAM questionnaire, scores range from 1 to 7 for possible options "strongly disagree" to "strongly agree" for 21 statements. The scores were summed up by dimensions, i.e., (D1) perceived usefulness, (D2) perceived ease of use, (D3) perceived enjoyment, (D4) intention of use, (D5) actual use, (D6) compatibility, (D7) attitude, and (D8) self-efficacy. The higher scores indicate higher technology acceptance.

The outcome variables (change in technology acceptance and OPQOL) were described using median. To assess the possible associations between OPQOL and technology acceptance, we computed Spearman's correlation coefficients [34]. First, we calculated the correlation between technology acceptance and OPQOL at baseline. Second, we measured both outcomes again at post-testing and computed a correlation between changes in technology acceptance and changes in OPQOL. All tests were two-sided and values of $p < 0.05$ were considered statistically significant. As our study was

considered an exploratory analysis, no correction for multiple testing was applied. All analyses were performed using the SPSS version 25.

Inductive content analysis was performed to analyze the qualitative data. This approach is suitable when the study is explorative or there are no existing studies in the research field [35,36]. Our study meets both criteria.

The interviews were firstly transcribed. The transcript was then read and analyzed in three main steps, i.e., open coding, creating categories, and abstraction [35]. During open coding, notes and headings were written down while reading the transcript. The next step was creating categories. These notes were grouped into categories to increase our understanding of the participants' use of Tangible Cup [37]. These categories helped us to describe participants' experience of using Tangible Cup, which links the impacts of using the Tangible Cup to the participants' technology acceptance and quality of life. Lastly, we performed abstraction to formulate the generated categories from the previous step into a main category. NViVo 12 was used to perform the three-step inductive content analysis process.

3. Results

3.1. Characteristics of Participants

Table 2 summarizes the characteristics of the participants. During our visits to the participants, they were observed on how they used their smartphone and/or tablet. Their ICT skills level was assessed based on these observations. Four participants (P17, P18, P19, and P20) decided to withdraw from the study after one month. Their data from the pre-testing were included in the data analysis and results.

Table 2. Summary of participants.

	Age	Gender	Education (Years)	ICT Skills
P1	79	Female	12	Basic
P2	74	Female	11	Basic
P3	82	Female	21	Basic
P4	77	Female	10	Basic
P5	76	Female	14	Very advanced
P6	81	Female	15	Basic
P7	82	Female	10	Advanced
P8	72	Female	12	Advanced
P9	82	Female	13	Basic
P10	81	Female	14	Basic
P11	81	Female	19	Advanced
P12	89	Male	17	Advanced
P13	77	Female	11	Advanced
P14	83	Male	14	Advanced
P15	83	Female	12	Advanced
P16	79	Female	12	Advanced
P17	77	Female	11	Advanced
P18	81	Female	8	Basic
P19	76	Female	13	Very advanced
P20	79	Female	10	Basic

ICT skills: Basic—manage to use smartphone and/or tablet with some problems; advanced—manage to use smartphone and/or tablet with minor problems; very advanced—manage to use smartphone and/or tablet without any problem.

3.2. OPQOL Questionnaire and TAM Questionnaire

The correlations between the total score of OPQOL and all the OPQOL dimensions with the technology acceptance total score before using Tangible Cup are presented in Table 3. No statistically significant correlation was found. By showing the correlation between pre-testing OPQOL and TAM, it can then assume that the correlation observed in post-testing is due to the use of Tangible Cup.

Table 3. Summary of Spearman's rank-order correlation (the correlations between the total score of older people's quality of life (OPQOL) and all the OPQOL dimensions with the technology acceptance total score before using Tangible Cup).

Correlations		
	Spearman's Rho	
	TAM (Total Score)	
	Correlation Coefficient	*p*-Value
OPQOL (total score)	−0.03	0.92
OPQOL _D1 (life overall)	−0.34	0.19
OPQOL _D2 (health)	0.20	0.46
OPQOL _D3 (social relationships and participation)	−0.41	0.12
OPQOL _D4 (independence, control over life, freedom)	0.05	0.86
OPQOL _D5 (home and neighborhood)	0.19	0.48
OPQOL _D6 (psychological and emotion well-being)	0.05	0.85
OPQOL _D7 (financial circumstances)	0.03	0.90
OPQOL _D8 (leisure and activities)	0.20	0.47
OPQOL _Q (First question evaluating quality of life as a whole)	−0.30	0.27

In terms of the changes in technology acceptance scores among participants from pre-testing to post-testing, 12 participants scored higher after using Tangible Cup, while four participants (P9, P13, P14, and P16) scored lower.

Referring to Figure 3, in terms of dimensions in technology acceptance, with the exception of D1 (perceived usefulness), D4 (intention of use), D5 (actual use), and D8 (self-efficacy), there were increments in all dimensions. D6 (compatibility) increased the most, followed by D7 (attitude), D2 (perceived ease of use), and D3 (perceived enjoyment).

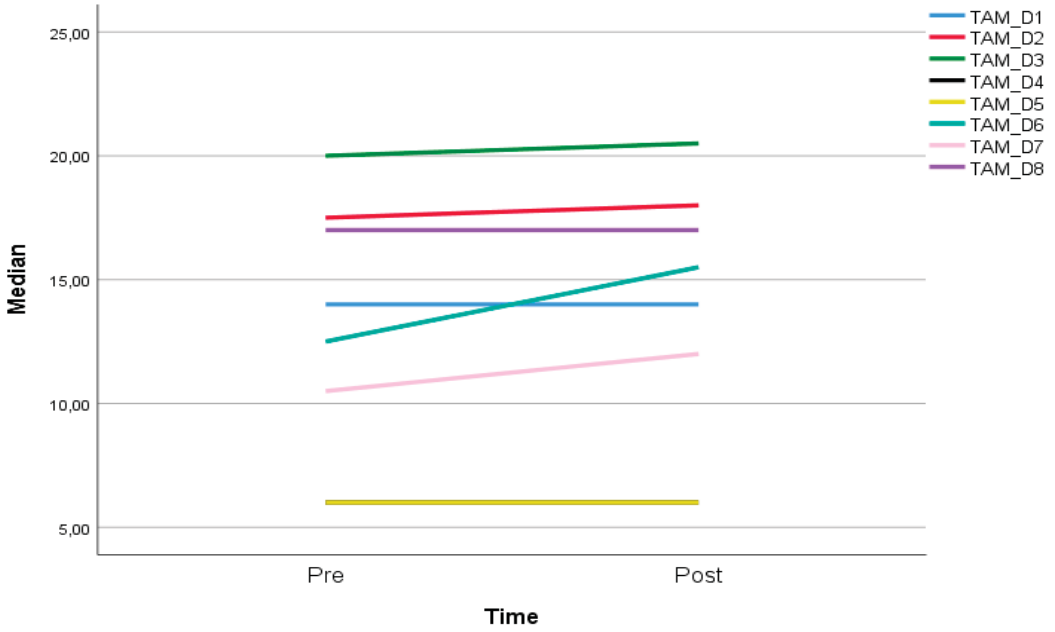

Figure 3. Median score of technology acceptance by dimensions at pre and post testing.

To study the changes in scales by dimensions, we summed up the changes from pre-testing to post-testing in negative scale, i.e., scale 1, 2, and 3 (Strongly disagree, Disagree, Somewhat disagree), and positive scale, i.e., scale 5, 6, and 7 (Somewhat agree, Agree and Strongly agree). Referring to Table 4, we can see that D6 (compatibility) and D7 (attitude) show the most improvement. D6 (compatibility) had an increase of 18.76% in positive scale (Scale 5, 6, and 7) and a decrease of 18.76%

in negative scale (Scale 1, 2, and 3). D7 (attitude) has a 21.86% increase in positive scale and a 9.38% decrease in negative scale.

When we look at individual questions, we can see that there were greater changes in some questions (Q2, Q4, Q5, Q6, Q7, Q8, Q9, Q11, Q12, Q13, Q14, Q15, Q16, Q18, Q20, and Q21) than in others. Q4, Q5, Q7 (D2—perceived ease of use) and 8, 9, and 11 (D3—perceived enjoyment) had two individual scales with changes of more than 18%, while the others had one. This indicates that the use of Tangible Cup had the greatest impact on these two dimensions. When we studied the changes in positive scale and negative scale as a whole, the greatest improvement was in Q7 (D2—perceived ease of use), Q15 and Q16 (D6—compatibility) while the largest decrease was in Q10 (D3—perceived enjoyment). Nine out of 16 participants gave higher scores when they were asked whether it is easy to learn to use digital communication tools (Q7). Half of the participants were more positive about the use of digital communication tools fitting their lifestyle (Q15) and their way of socializing with others (Q16). Table 4 summarizes all the scores by scale, question, and dimension in percentage.

In terms of the changes in OPQOL, none of the participants' OPQOL scores improved all the way from pre-testing to post-testing. Eight out of 16 participants had improved their OPQOL score at the mid-study, but the OPQOL scores decreased again at post-testing. The other eight participants' OPQOL score decreased at mid-testing. However, six of these eight participants scored higher at post-testing. There was no change in one participant's score while the other participants' OPQOL scores continued to fall. While studying the changes in the total scores of OPQOL, it is essential to mention that the use of Tangible Cup was believed to impact on some dimensions of the participants' OPQOL, but not on all of them, for instance, D7—financial circumstances.

Figure 4 illustrates the change in median score of OPQOL by dimensions (D1–D8) and Q (the first question in the questionnaire about the participants' quality of life as a whole) from pre-testing to mid and post-testing. D3 (social relationships and participation) is the only dimension showing negative correlation over time. Although there are changes in Q (overall quality of life), D1 (life overall), D4 (independence, control over life, freedom), and D7 (financial circumstances) from pre-testing to mid-testing, their median score remains the same when we compare pre-testing to post-testing. D2 (health) and D6 (psychological and emotion well-being) scored higher at the end of the study while D8 (leisure and activities) scored lower. There was no change in D5 (home and neighborhood) during the study.

The results of Spearman's rank-order correlation [34] are summarized in Table 5. Our data reveal some relevant statistically significant correlations. D5 in OPQOL (home and neighborhood) has a significant positive correlation with overall technology acceptance (TAM), D2 (perceived ease of use) and D8 (self-efficacy) in TAM. While Q of OPQOL (first question accessing overall quality of life) is negatively correlated with D5 (actual use), it is nonetheless positively correlated with D7 (attitude) in TAM. D4 in TAM (intention of use) is also positively correlated with OPQOL (total score) and D7 in OPQOL (financial circumstances). However, as mentioned earlier, the use of Tangible Cup is not expected to have any impact on the participants' financial circumstances.

3.3. Semi-Structured Interview

Using the three-step inductive content analysis, two main categories, i.e., "suitability of the Tangible Cup" and "potential of the Tangible Cup," were generated. Figure 5 illustrates the abstraction process in our content analysis and the generated categories.

Table 4. Summary of TAM questionnaire scores in 7-point Likert scales in percentage.

	1 Strongly Disagree		2 Disagree		3 Somewhat Disagree		4 Neither Disagree nor Agree		5 Somewhat Agree		6 Agree		7 Strongly Agree	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
D1. Perceived usefulness	12.50	14.58	6.25	4.17	12.5	8.33	18.75	10.42	20.83	31.25	14.58	22.92	14.58	8.33
D2. Perceived ease of use	3.13	1.56	9.38	3.13	12.5	21.88	34.38	10.94	12.50	31.25	23.44	31.25	4.69	0
D3. Perceived enjoyment	4.69	0	3.13	3.13	4.69	12.5	37.50	14.06	12.50	25.00	6.25	10.94	31.25	34.38
D4. Intention to use	0	0	0	0	0	6.25	31.25	12.50	12.50	0	31.25	43.75	25.00	37.50
D5. Actual use	0	0	0	0	6.25	0	6.25	6.25	25.00	12.50	37.50	37.50	25.00	43.75
D6. Compatibility	12.50	2.08	4.17	0	16.67	12.50	20.83	20.83	8.33	16.67	25.00	35.42	12.50	12.50
D7. Attitude	0	0	3.13	0	6.25	0	18.75	6.25	15.63	25.00	40.63	37.50	15,63	31.25
D8. Self-efficacy	0	0	2.08	0	8.33	2.08	0	2.08	25.00	27.08	45.83	50.00	18,75	18.75

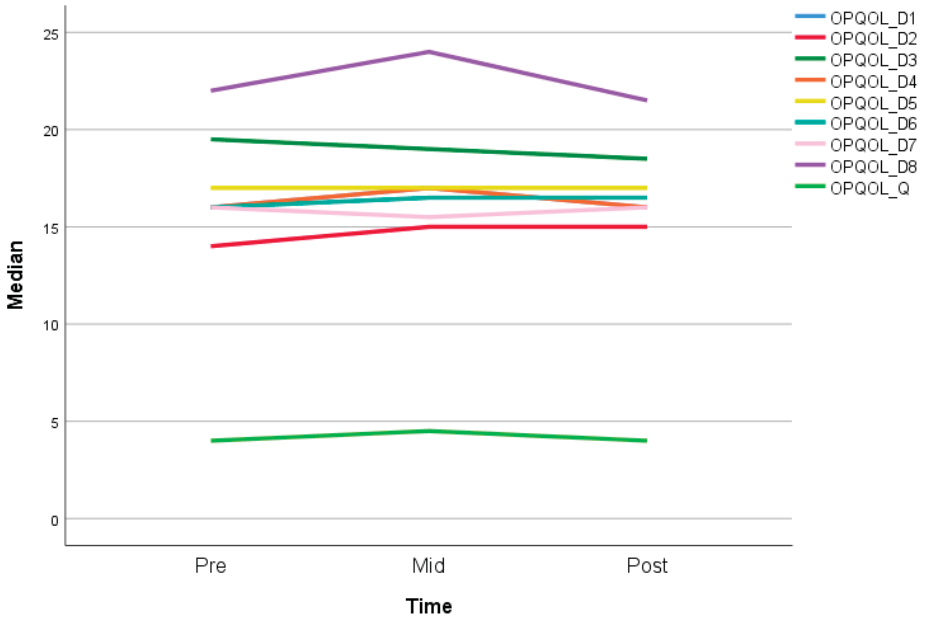

Figure 4. Median score of OPQOL by dimensions for pre, mid and post testing.

Table 5. Summary of Spearman's rank-order correlation (the correlations between the changes in all the OPQOL dimensions and the overall quality of life with all the TAM dimensions and overall technology acceptance after testing).

			OPQOL	OPQOL_D1	OPQOL_D2	OPQOL_D3	OPQOL_D4	OPQOL_D5	OPQOL_D6	OPQOL_D7	OPQOL_D8	OPQOL_Q
Spearman's rho	TAM	Correlation Coefficient	0.21	−0.17	0.07	−0.31	−0.11	0.62 **	0.21	0.06	0.29	−0.02
		p -value	0.44	0.53	0.79	0.24	0.70	0.01	0.44	0.82	0.28	0.95
	TAM_D1	Correlation Coefficient	0.05	−0.11	0.02	−0.44	0.01	0.35	0.11	−0.04	0.22	−0.23
		p -value	0.86	0.69	0.93	0.09	0.98	0.18	0.68	0.88	0.42	0.40
	TAM_D2	Correlation Coefficient	0.29	−0.17	0.19	−0.04	−0.14	0.59 *	0.34	0.16	0.14	−0.17
		p -value	0.27	0.54	0.49	0.89	0.61	0.02	0.20	0.55	0.60	0.52
	TAM_D3	Correlation Coefficient	0.19	0.19	−0.07	−0.20	0.29	0.14	−0.15	0.20	0.26	0.42
		p -value	0.48	0.48	0.80	0.45	0.28	0.61	0.57	0.45	0.33	0.10
	TAM_D4	Correlation Coefficient	0.64 **	−0.07	0.36	0.33	0.25	0.29	−0.07	0.60 *	0.06	0.21
		p -value	0.01	0.80	0.17	0.22	0.35	0.28	0.80	0.02	0.84	0.43
	TAM_D5	Correlation Coefficient	0.36	−0.03	0.32	0.08	−0.03	0.27	0.50	0.27	0.07	−0.51 *
		p -value	0.18	0.91	0.23	0.76	0.91	0.32	0.05	0.31	0.79	0.04
	TAM_D6	Correlation Coefficient	0.20	0.08	0.11	−0.07	−0.05	0.24	0.44	0.11	0.27	−0.37
		p -value	0.46	0.76	0.68	0.79	0.85	0.37	0.09	0.69	0.32	0.16
	TAM_D7	Correlation Coefficient	0.29	0.11	−0.01	0.01	0.02	0.39	0.11	0.06	0.17	0.70 **
		p -value	0.27	0.68	0.98	0.98	0.94	0.14	0.70	0.83	0.54	0.00
	TAM_D8	Correlation Coefficient	0.23	−0.47	0.19	−0.01	−0.25	0.54 *	0.24	0.20	0.05	0.07
		p-value	0.40	0.07	0.48	0.96	0.36	0.03	0.38	0.45	0.90	0.80

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

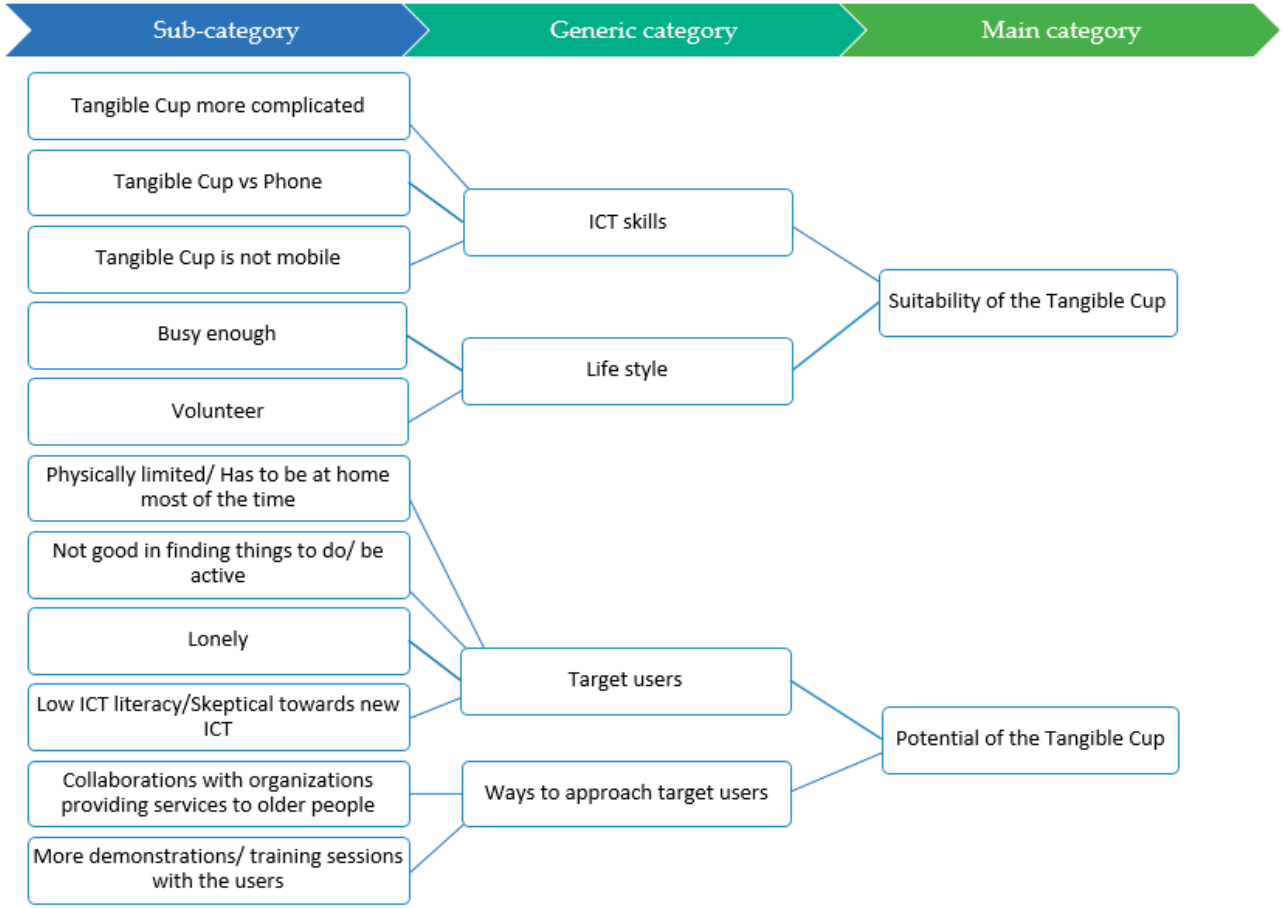

Figure 5. The abstraction process with sub-categories, generic categories and main categories

3.3.1. Suitability of the Tangible Cup

Four participants who withdrew from the study (P17, P18, P19, P20), provided the reasons that the Tangible Cup was not suitable for them. After using Tangible Cup for a month, they did not see the need and benefit of using the Tangible Cup and one mentioned the lack of male participants.

The participants have different levels of ICT skills (refer Table 2) and TUI might not be suitable for them. More than half of them are advanced IT users. Although their use of ICT is not entirely error and problem-free, they do use a smartphone on a daily basis. Some of them even use a tablet regularly. They therefore perceived the Tangible Cup as being more complicated as they could already use a touch screen without much difficulty. Out of a total of 16 remaining participants, seven switched from using the cup attachment as their TUI object to only using the tablet without a TUI object after our mid-study visit. They commented that without the cup attachment, it was easier to use the calling app with touch gestures on the tablet. Only four participants continued to only use the cup attachment throughout the study while the rest of them switched between using and not using the cup attachment.

> *"I liked it better when I was informed that I could use the tablet without these cups. I think so. Because then I only had to concentrate on one thing, so it was easier for me."*

Since the participants have had experience of using smart phones and tablets, they tended to expect the Tangible Cup to work like the devices that they were used to. This expectation caused some usability challenges during their three-month use of Tangible Cup. For instance, some of them misunderstood and thought the Tangible Cup worked like a phone. They expected the other users being called to hear the app ringing and answer their call immediately.

> *"I made a call to one person here, and it rang and rang, and no one picked up the phone. Then I tried two more, the same day! After that I sent a SMS to you (referring to the main author of this paper). I was quite irritated, that I had to sit here and waste my time on this thing!"*

The Tangible Cup is an Internet-based app and there were other external factors that influenced the ways the Tangible Cup app was used. For instance, we observed that some users did not log out properly after using the Tangible Cup. They thought that turning off the tablet's screen made them log out of the app. However, the app was actually still running. This resulted in many unanswered calls because the logged on users were not actually present.

Furthermore, the participants perceived the Tangible Cup as not being mobile. Although the whole Tangible Cup set is not heavy and easy to bring around, many users only used it at a certain place. They had the expectation that the Tangible Cup should be mobile like their smart phones.

> *"You have to sit down here with this thing and have it in front of you. But a phone is something you can have in your pocket and answer. You don't need to sit down here to deal with it, you can do it at the kitchen table, or in the bathroom or anywhere. You can even sit on the toilet and talk on the phone, right? You can't do that with this thing (Tangible Cup) here."*

Lastly, some of the participants expressed that they were already busy enough on a daily basis. Many of them participated in our study because they wanted to help other older people who might feel lonely and need someone to talk to. This resulted in too few users online at the same time. We therefore arranged two time slots which the participants should try to use Tangible Cup, i.e. 3 pm to 5 pm and 7.30 pm to 9.30 pm.

> *"I go to the gym, meet friends, take care of the grandchildren . . . .So I'm actually doing something all the time. So I don't always remember this (referring to the Tangible Cup) is laying there. And since it isn't ringing, I don't do anything with it. If it rang then I would pick it up, if you understand? But, that's how it is . . . "*

3.3.2. Potential of the Tangible Cup

Although most of the participants were not the target user group for the Tangible Cup, they recognized its potential. All of the participants agreed that the Tangible Cup had the potential to make a great impact if it could reach the target user group and all the features could be properly and fully developed. The primary characteristic of the target group is older people with limited physical ability or whose movement is restricted, which means they have to stay at home most of the time. Some of them are not good at finding things to do. So, while they cannot go out and make new friends, the Tangible Cup offers them the possibility to do that at home.

> *"I do know people who sit alone at home the whole winter, because it's so slippery right? And they do become very lonely at home by themselves. Because their friends might not be able to go out either. So then it is quite a crisis for them, some people I know."*

> *"I have an uncle who is 95 years old. He is bad with his feet, but his mind is totally fine. So my uncle in Drammen could certainly have enjoyed a system like this."*

The Tangible Cup could be a great help to older people who feel lonely. Some participants mentioned that as they become older, there are fewer people in their social circle. So for those who are getting older and older and feel lonely at times, the Tangible Cup can help them to make new friends.

> *"It would certainly be suitable for very lonely people too, but there has to be two people. So one of them could be very lonely, and the other could be relatively healthy and active. It will be a combination where one person doesn't have much going on and can then call the other one."*

In addition, the Tangible Cup may be suitable for older people with low ICT skills or who are skeptical to new technology. When one becomes older, one might suffer from memory decline and therefore, older people become more forgetful [38,39]. The use of cup coasters and a cup attachment to control the app in the tablet was regarded as easy and required less effort to remember, and could thus be an easier approach for non-native older ICT users.

> *"If you are in a phase where you can easily select someone you know, and you don't have to think about anything other than that cup and those cup coasters, because the rest sorts itself out, right. So I see the point, I do."*

In order to reach the right target user group in future, we need to collaborate with organizations that have experience of providing services to older people. The older users who use their services trust them and have faith in them. In addition, these organizations shall also become users of Tangible Cup. The older users can reach them easily by using Tangible Cup.

> *"I think the idea is good, but one has to find a way to use it. I think there's certainly many people sitting alone (at home), and they would then have someone to call, three, four, five people to call. Seeing the names displayed there (referring to Tangible Cup), when they're logged in. So I think it can be useful, something like a social service, absolutely . . . I think."*

The use of Tangible Cup can be extended from homes to places such as senior centers and community centers. More demonstrations or training sessions could be held with users at their local senior centers to encourage older people to use it. They can learn how to use Tangible Cup as a group, and use it there regularly with others.

> *"We also do that at the senior center, so there are more people working with it. But most of them are only in one place, not at someone's home. When one is using it alone (at home), one loses courage quickly, one does that."*

Arrangements can be made to enable people to be logged in to Tangible Cup with other users at other senior centers at the same time. The idea is similar to the sessions we have previously arranged for the participants. It has proven useful to get the users online at the same time.

4. Discussion

To the best of our knowledge, no previous research has been conducted on the use of TUI as an intervention to study its impact on older people's technology acceptance and quality of life, and the associations between these two outcome measures. We have presented the quantitative and qualitative results in the previous section. In this section, we present the interpretation of our results after analyzing both the qualitative and quantitative data as a whole.

4.1. Impact of TUI on Older People's Technology Acceptance

The study shows that 12 out of 16 participants' technology acceptance improved after using Tangible Cup. Similar to Davidoff, Bloomberg, Li, Mankoff and Fussell [21]'s and Spreicer [22]'s findings, TUI has the potential to increase older people's confidence in using new ICT, especially for those with low ICT literacy. Chen and Schulz [40] drew the conclusion that ICT is not a one-solution-for-all with respect to older people, who make up a large and diverse population [24,41]. They can be very different from one another when it comes to their preferences, abilities, demographic background, social status etc. A single TUI application such as the Tangible Cup is not therefore necessarily suitable for all older people. This is demonstrated by the scores in D1 (perceived usefulness), D4 (intention of use), and D5 (actual use) in our study. D1 (perceived usefulness), D4 (intention of use), D5 (actual use) indicate that the use of Tangible Cup might not be suitable for the participants. P12-P16 are among the participants that scored the lowest improvement in these three dimensions, and they are all advanced ICT users. Three out of four participants (P13, P14, and P16) who scored lower in technology acceptance after using Tangible Cup are also advanced ICT users. They found TUI a more challenging interface to use as they already mastered the use of touch screen. The same goes for P17 (advanced) and P19 (very advanced) who withdrew from our study, as they did not find the Tangible Cup useful as they could already perform all their social interaction using their touch screen smart phones and tablets.

D7 (attitude) is one of the dimensions that shows the most improvement. The scores for Q17 and Q18 (D7 in TAM), together with the positive feedback from the participants about the potential of Tangible Cup in the semi-structured interviews, indicate that the use of Tangible Cup can improve older people's attitudes to using new ICT. Mitzner et al. [42] reported that most older people are positive, rather than negative, in accepting technology, as long as the technology does not cause inconvenience, harms their security, or is unhelpful. Despite the challenges they faced in using Tangible Cup, the participants managed to see the potential of Tangible Cup, which could possibly explain their higher score in D7 (attitude) in TAM.

D6 (compatibility) in TAM had the biggest increase in its median after the study, and all three questions in D6 (Q14, 15, 16) had significant positive changes. Compatibility refers to the way users value a product, and how the product fits their needs and lifestyle [43]. Tangible Cup, which was inspired by the Norwegian coffee-drinking culture [24], fits well with the participants' lifestyle (Q15) and has the potential to work well as a communication tool (Q16) fitting well with their social life (Q14). Nevertheless, similar to the finding of a study investigating older people's participation in video user-created content (video UCC) [44], the increase in compatibility (D6 in TAM) has neither increased the participants' intention to use nor actual use in technology acceptance (D4 and D5 in TAM). Both the results of the semi-structured interviews and the TAM questionnaire indicate the same, i.e., that the participants did not fit exactly into the Tangible Cup target user group. The participants highlighted the usability challenges in terms of using Tangible Cup, as they were already familiar with using touch gestures on their smartphones and tablets. Thus, they did not use their Tangible Cup very often, and did not improve much with respect to their actual use (D5, Q13) in TAM.

However, all of the participants agreed in the interviews that the Tangible Cup could be useful and beneficial to a certain target user group, which includes those who need new friends, have low ICT literacy and probably restricted physical movement as well as a need for ICT training courses. Blažun et al. [45] concluded that using ICT as a means of encouraging social and physical activities among older people is promising. Their findings show that older people who are less ICT literate and

socially and physically active have a higher chance of benefitting from the positive effects of adopting ICT. Tangible Cup is probably suitable for older people with these characteristics.

4.2. Impact of TUI on Quality of Life

Our results showed that there were changes in the participants' quality of life, but none of them are statistically significant. The concept of "quality of life" is broad and yet complex, and affected by a person's physical health, psychological state, level of independence, social relations, personal beliefs, and relationship to the environment [3]. In order to provide an accurate instrument to measure older people's quality of life, Bowling [32] has specifically developed the OPQOL questionnaire, which was used in our study. This questionnaire has been used in studies predicting adverse health outcomes [46], investigating the associations between frailty and quality of life [47], etc. However, it has not been used in any studies using ICT as an intervention. We acknowledge that the use of Tangible Cup could probably only affects certain aspects of the participants' quality of life, i.e., social relationships and participation, and psychological and emotion well-being.

The analysis of OPQOL data shows that the median score of D3 (social relationships and participation) in OPQOL decreased consistently from pre-testing to post-testing. This decline can be explained using the results of the semi-structured interviews. Most of the drop in the participants' D3 scores was probably due to the challenges they faced in using Tangible Cup outweighing the social relationships and participation they had gained. In the semi-structured interviews, many of them voiced their frustration about not getting an answer when they called someone, not being able to bring the Tangible Cup around etc. Some of the participants had high hopes and expectations when they started using Tangible Cup. However, because of these frustrations, they were disappointed by the use of Tangible Cup and this resulted in a lower score in D3. All of them scored lower in Q10 in the TAM questionnaire after the study, as they found it less pleasant to use ICT tools after using Tangible Cup. This could correspond with Dickson and Gregor [41]'s argument that the positive effects of using computer systems among older people can be misleading. It is important to recognize that these positive effects might be due to other factors than purely the use of computers. For instance, training or support from voluntary computer course instructors, teachers or supporting volunteers that increase the social relationships and participation of older people.

It is worth mentioning that D8 (leisure and activities) increased at mid-testing but decreased back to its original score at post-testing. According to Dattilo et al. [48], older people perceived doing voluntary work as a type of leisure activity that can be meaningful and enjoyable. With particular reference to Q31 and Q32 (D8) in the OPQOL questionnaire, their mid-testing scores increased a lot compared to the pre-testing scores. As indicated in the semi-structured interviews, most of the participants were more interested in helping others who needed to talk to someone. They wanted to play the role of call recipient. The use of Tangible Cup was seen as voluntary work, which made them feel more involved in things around them (Q31) and gave them a role in their life (Q32). They therefore scored higher in D8 (leisure and activities) at the beginning of the study as they felt more excited about this voluntary work. As the study progressed, they found that the other participants did not really need their help, and they started to feel less passionate about their role as volunteer. Hence, the D8 (leisure and activities) scores, i.e., Q31 and Q32 dropped drastically at post-testing.

4.3. Association between Technology Acceptance and Quality of Life Before Testing and Their Changes After Testing

The strength of correlations was interpreted according to Cohen's classification where 0.10 to 0.29 is weak, 0.3 to 0.49 is moderate, and 0.5 to 1.0 is strong [49]. No significant correlation was observed between the participants' technology acceptance and quality of life prior to using Tangible Cup. However, after using Tangible Cup for three months, the results of the Spearman's rank-order correlation in SPSS indicate that some changes in the dimensions in technology acceptance are statistically significant associated with some changes in the dimensions in the OPQOL.

In a study evaluating the effect of a telecare service on quality of life and technology acceptance among older people, Chou, Chang, Lee, Chou, and Mills [19] found that the user attitude to using the telecare service has the highest correlation with the quality of life. Our results indicated the same, with a correlation coefficient of 0.69 showing the highest correlation (Q in OPQOL—first question accessing overall quality of life with D7—attitude in TAM). When the participants were more positive to using ICT (Q17 and Q18 in TAM), they might feel more positive generally and give a higher score when they assessed their quality of life as a whole. The positive attitude should have made them use the ICT tools more often (D5—actual use, Q13 in TAM). However, that was not the case. The actual use of Tangible Cup correlated negatively with their quality of life. Our qualitative data could explain this; as most of the participants were already leading busy lives and the use of Tangible Cup neither fitted their ICT skills nor their lifestyle.

The correlation results between D5 in OPQOL (home and neighborhood) with overall technology acceptance (TAM) (correlation coefficient = 0.62), D2 (perceived ease of use) (correlation coefficient = 0.59) and D8 (self-efficacy) (correlation coefficient = 0.54) in TAM, might indicate that the older participants who believed that they were able to use Tangible Cup perceived it as easy to use and thus scored higher in TAM, would feel better and happier in the home and neighborhood they were living in. The participants only used the Tangible Cup in their own home. The use of Tangible Cup, as a form of ICT intervention could help to make the participants feel they were getting more pleasure from home (D20 of OPQOL). Findings in a study by Christophorou et al. [50] confirmed that ICT services could contribute to enabling older people to stay active and independent while living at home. Some participants commented that the use of Tangible Cup would be suitable for those who had problems getting out of their homes, for instance, due to physical disabilities or bad weather in the winter and slippery conditions outside.

The Spearman rank-order correlation results also show that D4 in TAM (intention of use) is positively significantly correlated with the OPQOL total score (correlation coefficient = 0.63). When older people are more keen to use ICT tools (Q12 in TAM), they would probably perceive the use of ICT as contributing to a better quality of life. Likewise, when they have a better quality of life, they tend to be more positive to using ICT, especially when they believe that the two are interrelated. This supports the finding by Chou et al. [19] that older adults who have a more positive attitude to accepting and using telecare services have a better quality of life. Using the Internet to establish new contacts and maintain social relations has been found to have a great impact on older people's quality of life [10]. The use of Tangible Cup, as a form of Internet-based ICT tool that can connect older people to other new people, has confirmed the positive impact on quality of life.

ICT as an intervention in reducing older people's social isolation has helped older people through four mechanisms, i.e., connecting to the outside world, gaining social support, engaging in activities of interests and boosting self-confidence [40]. Via our semi-structured interview, we received positive feedback about the potential of Tangible Cup. Those whose needs can be met through using Tangible Cup, can benefit from using it via the above-mentioned mechanisms. Two of the participants mentioned that they would like to further develop a friendship after their conversation and meet up in person. When an older person is open to accepting the use of ICT, the benefits of using ICT to enhance their quality of life can be promising.

4.4. Limitations

An obvious limitation of this study is the research design. A clinical randomized study could contribute to examining the effectiveness of the Tangible Cup as an intervention. By using an intervention group and a control group, we may be able to identify stronger evidence for the effects of using Tangible Cup. In terms of study duration, Tangible Cup was only used for three months and the participants agreed that such a short time could have little impact on their quality of life. Using Tangible Cup for a three-month period is seen as a one-off trial, so the generalizability of the results

is limited, as suggested by Chen and Schulz [40] in their review of the effect of ICT interventions on reducing older people's social isolation.

OPQOL is a suitable instrument for measuring the multidimensional impacts on older people's life as a result of a health and social intervention [51]. However, there were other factors that we had no control over, i.e., the participants' taking holidays, participating in social activities, their state of health etc. While using Tangible Cup, the participants also used other ICT tools as well, such as their own smartphones, tablets, iPads, personal computers, and laptops throughout the study. These external factors affected the way they perceived ICT use and thus, their scores in the TAM and OPQOL questionnaires. In addition, it is worth mentioning that the OPQOL questionnaire representing eight dimensions [32] shows the complexity on how older people's quality of life can be influenced. Thus, one might question on to what extend quality of life among older people may be influenced by the use of technology in terms of different dimension of their OPQOL.

The small sample size limits the precision of estimation, and thus reduces the chance of detecting the true effect of Tangible Cup as statistically significant [52]. We only managed to recruit 20 participants after approaching more than 100 potential participants. When we tried to recruit participants, we realized that those who actually had low ICT skills and might feel socially isolated were skeptical about joining our study. They felt uneasy about being labelled as needing help either with their ICT use or social life, and thus showed no interest in participating in our study. A study conducted by Zickuhr and Madden [53], found that most of the older adults stated that they were just simply not interested in using the Internet or email. All the participants in this study have used ICT for many years and were therefore more positive to trying out new technology.

The participants did not accurately represent the target population, which means our sample is probably biased. Bilotta et al. [46] used the OPQOL questionnaire to predict several adverse health outcomes in older outpatients living in the community in Italy. In this study comprising a total of 210 older participants, the mean for OPQOL total score was 116.20. Another study conducted by Kojima et al. [47] to investigate the associations between baseline frailty status and subsequent changes in QOL had the mean for OPQOL at 130.82 (n = 363). The mean for the participants' pre-testing OPQOL total score is 141.81 (n = 16, standard deviation = 13.20). The OPQOL total score before the use of Tangible Cup ranges from 119 to 167. This clearly indicates that the participants already had a very good quality of life before the intervention. The possibility of improving the participants' quality of life was therefore lower.

The diversity of the participants' socio-demographic backgrounds in our study is not well-represented. Previous studies have shown that socio-demographic variables are associated with older people's use of ICT [54,55]. The participants in our study were recruited from another project that we had previously conducted in several senior centers located in Oslo. These senior centers are residential-area based and the participants who went to the same senior center therefore had similar socio-demographic backgrounds. They were all ethnic Norwegians and none of them were novice ICT users (refer ICT skills in Table 2). They had all lived in the City of Oslo for some time and access to ICT had never been a big issue for them. This recruitment approach has failed to reach the target user group.

Another limitation is that the validity of our instrument, the OPQOL questionnaire, is still unknown. The OPQOL questionnaire was developed by Bowling [32] and it has the potential to be used as an outcome measure to promote well-being and more active aging. This is in line with our aim, which is to use TUI to improve older adults' quality of life and technology acceptance. The OPQOL questionnaire was chosen from among other QOL questionnaires for this very reason, because older people are our target group [56]. However, this questionnaire has never been used in Norway. We translated the questionnaire into Norwegian based on the guidelines developed by Beaton, Bombardier, Guillemin and Ferraz [33] and this Norwegian version of the OPQOL questionnaire was not validated before our data collection. We have now completed a study on the validation of this questionnaire using the methodology described by Hak et al. [57]. The methodology is a three-step test interview

that involves participants' self-completion of the OPQOL questionnaire, observation and cognitive interview. The data are currently being analyzed and will be presented in a forthcoming publication.

Last but not least, the Tangible Cup usability issue limited the participants' use of the intervention. From our observations during visits to them, some of the participants did not always remember how to use Tangible Cup. When they did not use Tangible Cup correctly, certain functions did not work and they became frustrated. For instance, instead of putting the cup attachment on the search contacts coaster to find other online users, they put it on the call coaster. Although the participants were briefed about how to use Tangible Cup, they still needed guidance from time to time. In order to maximize the effects of using Tangible Cup, or other ICT tools as an intervention to address the issue of social isolation among older people, training is essential to address the special needs of these older ICT users [40]. Customized training and group activities must be provided on a regular basis to keep them motivated and help them to remember.

5. Conclusions

In this paper, we present a longitudinal study where 20 participants used a TUI prototype, Tangible Cup for three months. We have found that the use of Tangible Cup has improved the technology acceptance of some participants, but no statistically significant changes have been observed. Although the scores in the OPQOL questionnaire did not indicate much improvement in their quality of life, all of the participants agreed that Tangible Cup has the potential to improve the quality of life of other older people for whom TUI may be suitable. This group of older people might be physically limited and restricted in terms of mobility, not good at finding things to do, feel lonely and have low ICT literacy. Some statistically significant associations have been found between changes in technology acceptance and quality of life after using Tangible Cup. However, further investigation is required to validate them. We are currently further analyzing the qualitative data using a hermeneutic interpretation approach, and the qualitative data analysis exploring the participants' experience of using the Tangible Cup might disclose more positive outcomes related to their quality of life.

This study has shown the potential of TUIs in improving technology acceptance and quality of life. However, it is important to target the right group of older people. Our current study only lasted for three months, which might explain why the Tangible Cup had no observed impact on the users' quality of life. In the future, we will include older people with low/no ICT skills, focus on the target user and allow the participants to use Tangible Cup for a longer period of time in order to understand the impact of Tangible Cup on their quality of life.

In addition, the findings from this study have implications for both technology designers and developers, and clinicians and health managers. By showing the advantages of using TUI in the development and organization of clinical healthcare services for older people, digital health care services can consider TUI as a more intuitive user interface for older users.

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Article IV:

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Exploring tangible user interface for social interaction and quality of life: The experiences of home-dwelling older adults

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Background: Social relationships are an important element in our quality of life, and good social interaction can contribute to flourishing social relationships. Information and communications technology (ICT) has been developed to enhance our social interaction, but older adults encounter challenges in connection with its use. Some older adults might find it challenging to use small icons and buttons on touch screen devices, mouse and keyboard that require hand-eye coordination and touch screens that require sensitive fingers etc. Tangible user interface (TUI) enables users to interact with digital information through everyday physical objects. Hence, TUI can be a more intuitive user interface for older adults. However, little is known about the potential of TUI in relation to social interaction and quality of life in older home-dwelling adults. **Research aim:** In this study, we aim to investigate home-dwelling older adults' experience of using a TUI application with respect to social interaction and quality of life. **Methods:** The TUI application, Tangible Cup, was used by 20 older participants in a 12-week pilot study. The study design was based on a semi-structured interview and the interview data were analysed using a hermeneutic interpretation approach. **Results:** The results show that some participants managed to have enjoyable conversations with others despite the challenges in using Tangible Cup. The participants reflected on reasons for and against using Tangible Cup, and there is a mismatch between the participants' attitudes and behaviour in relation to using Tangible Cup and its design. **Conclusions:** Based on the results, the characteristics of older adults who can benefit the most from using TUI and TUI designs that are suitable for them are summarised. By providing better understanding of how older people use TUI, the findings from this study could inform better TUI design for older people's social interaction and quality of life.

Keywords: tangible user interface, older adults, social interaction, quality of life.

INTRODUCTION

With an ageing population, many studies have focused on the quality of life of older adults (Bergland et al., 2016; Boz & Karatas, 2015; Gerino, Rollè, Sechi, & Brustia, 2017). In accordance with the World Health Organization (WHO), quality of life is defined as 'an individual's perceptions of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations standards and concerns' (Group, 1993). It is largely agreed that the concept of quality of life should be considered a multidimensional construct comprising a number of core domains including physical,

psychological and social aspects (Felce & Perry, 1995). These core domains are influenced by personal characteristics and by environmental and contextual factors (Verdugo, Schalock, Keith, & Stancliffe, 2005).

The social aspect is an essential element in older adults' quality of life and healthy ageing (Corner, Brittain, & Bond, 2006). Older adults identify their own and others' health, family relationships, social activities and other relationships as some of the most important areas of life (Bowling, 1995). Older adults' social interaction can promote healthy ageing by acting as a buffer against the negative effects of ageing, regardless of whether they interact with friends or family members (Huxhold, Miche, & Schüz, 2013). People with more social networks tend to be more optimistic, feel better and are therefore healthier (Antonucci, 2001; Cohen & Janicki-Deverts, 2009).

Research has shown that Information and communications technology (ICT) could contribute in enhancing our social interaction. Technologies such as mobile apps, smart phones, tablets etc. have been designed to support social networks between friends and family, and enhance the social interaction between them. However, due to the diversity in older adults, not all ICT solutions are suitable for older adults (Bong & Chen, 2019; Chen & Schulz, 2016). Many of our current ICT solutions use graphical user interface (GUI). GUI is a type of user interface that enables users to interact with their electronic devices through graphical elements, icons and symbols, e.g. visual keyboards on smartphones and tablets, icons in mobile apps and computer-based software. Although GUI has made the interaction between humans and electronic devices easier by eliminating the need for text-based user interfaces such as command lines, it is not always intuitive and user-friendly, especially for older adults. Usability issues such as understanding icons and the size of buttons and icons were identified in a study evaluating six mobile launchers for older adults (Al-Razgan, Al-Khalifa, & Al-Shahrani, 2014). Existing mobile instant messaging apps were evaluated and some GUI elements did not appear to be intuitive for older ICT users (Bong & Chen, 2015).

In 1997, Ishii and Ullmer (1997) introduced tangible user interface (TUI). Their aim was to make the digital world truly invisible and ubiquitous by coupling digital information to our everyday physical objects and environments. Through TUI, older adults can interact with digital information by using familiar physical objects instead of graphical elements. This could minimise the difficulties they encounter interacting with GUI, as suggested by Davidoff, Bloomberg, Li, Mankoff, and Fussell (2005) and Spreicer (2011), thus enabling TUI to contribute to more intuitive and effortless use of ICT. When the use of ICT is enhanced, more frequent use could improve quality of life (Boz & Karatas, 2015; Christophorou et al., 2016; Gustafson et al., 2015). Although TUI has been adopted in many studies, our review shows there is limited summarised evidence of the its effects on enhancing older adults' social interaction (Bong, Chen, & Bergland, 2018).

There is currently limited knowledge on older adults' experience of using TUI and the perceived barriers that may hinder their use of TUI for social interaction and quality of life. To address these gaps in the literature, we conducted a pilot study using a qualitative approach to investigate how home-dwelling older adults experience a TUI application in relation to their social interaction and quality of life in a 12-week TUI intervention. By exploring older adults' use of a TUI application, we hope to provide better understanding of the ways they use TUI. The findings could provide useful information for reducing amendable barriers to using TUI, and thus inform better design for older people's social interaction and quality of life.

Tangible Cup

Using a user-centered and co-design approach, a TUI application, Tangible Cup, has previously been designed for older adults' social interaction and quality of life (Bong & Chen, 2019). The main feature of Tangible Cup is to make calls. The participants did not know each other at the beginning of the intervention.

The idea of Tangible Cup was inspired by the Norwegian coffee drinking culture where a coffee cup was identified as a familiar everyday physical object for older adults. It consists of a cup attachment (under the

cup), five cup coasters (from left to right: *log out, log in, search contacts, call* and *end call*) and a tablet (see Figure 1). There is an app on the tablet displaying the name and age of the users, the city the users live in and the status (logged in or logged out) (see Figure 2).

Figure 1. Tangible Cup

As shown in Figure 2, the logged in status is indicated by a telephone icon behind the name while the logged out status is without the telephone icon. The users who were logged in were expected to make calls to the other logged in users and the users who received calls could either accept or reject the calls (we address them as the 'caller' and the 'recipient' in the rest of the article). We hoped that by making calls to people they did not know in the calling group, the participants could make new friends and enhance their social well-being.

Figure 2. Interface of Tangible Cup app on tablet

The original intention was for the users to attach the cup attachment to the bottom of their own cup. However, with the safety of using Tangible Cup in mind, we asked the participants to just use the cup attachment without a cup. They had to move the cup attachment and place it on the corresponding cup coasters to perform desired actions. An app was installed in the tablet, whereby the participants' interactions with the cup attachment and cup coasters would trigger the actions performed on the app.

METHODS

Study design

A qualitative approach was adopted in this study, with the aim of exploring and describing the participants' views on and experience of using TUI. Semi-structured interviews were conducted to collect the qualitative data. According to Bottorff (2015), the qualitative inquiry has unique advantages that contribute to the exploration of the complex process of research translation. Our qualitative approach explores the

participants' communication, expectations, opinions, attitudes, process, and, most importantly, interaction and relations. These are the core components of clinical knowledge (K. Malterud, 2001).

Interview

The TUI intervention, Tangible Cup, has never been used over a long period of time without any supervision or guidance from the researchers. The main focus of the interview was to explore the 20 participants' views and experiences, and how they used Tangible Cup independently. Thus, after introducing them to Tangible Cup and demonstrating its use, the users were given a user guide to refer to, and were assured they could contact us whenever they faced problems. A semi-structured interview guide was used. We conducted three rounds of interviews, i.e. pre-study, mid-study and post-study. In the pre-study interview, the participants were asked about their use of ICT, their social interaction and social life, their perception of a good life (quality of life) and their expectations of using Tangible Cup. In the mid-study interview, we asked them about their experience of using Tangible Cup and the ways they used it. Finally, the post-study interview focused on their feelings about and experiences of using Tangible Cup, changes in their lives after using it and their opinions about using it. Examples of interview questions were: 'Tell me your experience of using ICT/Tangible Cup'?, 'What is the best/worst part of your social life?', 'How do you think the conversations you have had contribute to your quality of life (i.e. a better life)?', 'How do you feel after using Tangible Cup?' and 'How has ICT/Tangible Cup contributed to your social life?' Follow-up questions were asked when necessary to clarify and elaborate on their answers.

Recruitment and participants

We recruited a total of 20 older adults (2 men and 18 women) to participate in the study. The potential participants were identified based on a previous project related to quality of life, nutritional status, physical condition and pain, and mental and social function of senior centre users in Oslo. They were briefed about the project during a phone call and asked whether they were interested in taking part. We aimed to recruit all the participants for the 12-week Tangible Cup intervention, with the aim of reaching data saturation (Creswell & Poth, 2017; Ness, 2015). We recruited 20 participants, which is more than the number suggested by Guest, Bunce, and Johnson (2006) to achieve data saturation. Our participants' ages ranged from 72 to 89 and their education from 8 to 21 years.

We originally only included people who lived alone, but due to the difficulty of recruiting male participants who lived alone, we included one man who was still living with his wife (P14). Other inclusion criteria were being 70 years or over and being able to walk independently with or without an assistive device indoors. The participants were randomly divided into two groups. Each group comprised 9 women and 1 man. All the participants live in the city of Oslo. Their ICT skills and how they used ICT, such as smartphones and tablets, on a daily basis were observed and assessed during our visits. 'Average' IT skills indicates that they could use ICT with some problems; 'advanced' describes those who use ICT with minor problems; while 'very advanced' users face almost no problems using ICT on a daily basis.

Along with this study, the participants were also asked to complete the Older People's Quality of Life (OPQOL) questionnaire. Bowling (2009) developed the OPQOL questionnaire as a new measure of quality of life for older adults, with the aim of evaluating the quality of life of older adults in eight dimensions, i.e. (a) life overall, (b) health, (c) social relationships and participation, (d) independence, control over life, freedom, (e) home and neighbourhood, (f) psychological and emotion well-being, (g) financial circumstances and (h) leisure and activities. The detailed results of this questionnaire are presented in another publication. In this paper, we present the participants' pre-study and post-study OPQOL total scores, together with their demographic information (see table below).

Table 1. Participants' demographic information and Older People's Quality of Life (OPQOL) scores before and after 12-week use of Tangible Cup

	Age	Gender	ICT skills	Education (years)	Relationship status	Pre-study OPQOL total score	Post-study OPQOL total score
P1	79	F	Average	12	Widow	132	125
P2	74	F	Average	11	Widow	119	124
P3	82	F	Average	21	Widow	167	159
P4	77	F	Average	10	Widow	142	138
P5	76	F	Very advanced	14	Widow	136	147
P6	81	F	Average	15	Widow	135	141
P7	82	F	Advanced	10	Widow	147	155
P8	72	F	Advanced	12	Widow	134	138
P9	82	F	Average	13	Widow	132	128
P10	81	F	Average	14	In a relationship	148	158
P11	81	F	Advanced	19	Widow	139	136
P12	89	M	Advanced	17	Widow	124	120
P13	77	F	Advanced	11	Widow	130	133
P14	83	M	Advanced	14	Married	158	150
P15	83	F	Advanced	12	Widow	154	154
P16	79	F	Advanced	12	Widow	156	155
P17*	77	F	Advanced	11	Widow	N/A	N/A
P18*	81	F	Average	8	Widow	N/A	N/A
P19*	76	F	Very advanced	13	Widow	N/A	N/A
P20*	79	F	Average	10	Widow	N/A	N/A

*Indicates the participants who withdrew after four weeks of the study. Their withdrawal from the study is discussed in detail in the 'Results' section.

Ethical considerations

The study was pre-approved and registered by the Norwegian Centre for Research Data (NSD), reference number 253545. After receiving written and oral information, all the participants gave their written and informed consent. This included the assurance that they could withdraw their consent without consequences at any time and that they were guaranteed confidentiality.

Procedure and data collection

A Tangible Cup set was given to the participants during the first visit to their home. We briefed them about the project and demonstrated how to use Tangible Cup. Once they agreed to participate in the study, they were asked to give their informed consent and we asked them to use Tangible Cup whenever they wanted to. They were then interviewed.

We conducted the mid-study visit after six weeks. Before the mid-study visit, some participants needed extra visits because they were having problems using Tangible Cup. During this visit, we discovered that most of them were experiencing problems contacting the other Tangible Cup users. Some participants did not get an answer when they called the other online users. In addition, only a few of them were logging in and using Tangible Cup at the same time. To address this issue immediately, we suggested the participants could try

to use Tangible Cup during two time slots, i.e. 3pm to 5pm and 7.30pm to 9.30pm. The post-study visit was conducted after another six weeks, which was 12 weeks after the pre-study visit.

Data were collected from 9 January to 3 May 2019. A total of 56 individual interviews were conducted. Four post-study interviews were not conducted due to four participants withdrawing from the study after the mid-study visit. They were however interviewed prior to their withdrawal. The interviews were conducted at the participants' homes with only the interviewer and the participant present. All the interviews lasted less than an hour.

It is important to mention that during these visits, all the participants were observed using Tangible Cup and these observations were noted down. Based on these observations, follow-up questions were asked during the semi-structured interview when necessary, which were also used to help us understand and interpret the qualitative data.

Data analysis

A hermeneutic interpretation approach, i.e. an approach that seeks to understand the meaning of the text, over and above how it was created, was used to analyse the data (Birkeland & Natvig, 2009; Lindwall, von Post, & Eriksson, 2010). For this data analysis, Ricoeur's theory of hermeneutic interpretation was referred to, which is closely connected to the concept of the text, and the principal features of the theory can be derived from the characteristics of written discourse (Ricoeur, 1981, p. 14). Important background information for the data analysis are that a user-centered design approach was used to design Tangible Cup, based on input from a focus group consisting of older adult volunteers, and it was subsequently co-designed and tested by older adult volunteers (Bong & Chen, 2019). However, the final version of Tangible Cup has never been used and tested by a group of users over a long period of time. Since the older participants had very little knowledge of using TUI, using Ricoeur's hermeneutic interpretation allows 'more interpretation and guessing' in our data analysis. As explained by Ricoeur (1981, p. 14), 'the construal of meaning may indeed result in more than one interpretation of a text, in which case the imminent conflict must be subsumed to a process of argumentation; but this is a process…'. Thus, by using a hermeneutic interpretation approach, we could make interpretations and gain an in-depth understanding of the researched phenomenon (Alvesson & Sköldberg, 2017, pp. 122-132), in this case the impact of Tangible Cup on older adults' social interaction and quality of life.

All the interviews were audio recorded and transcribed verbatim. They were then read five times using hermeneutic text interpretation (Lindwall et al., 2010). The first reading was to integrate the text with the reader and 'Let the text itself speaks' (Gadamer, 1989). Any interpretation or analysis was avoided during this reading, as the focus was to understand the text and ask what the text had to say. In our second reading (the fusion of horizons), interpretations and more questions were raised. The aim of the third reading was to understand the text and to answer questions that could lead to another element of understanding. Primary, secondary and basic themes were summarised in the fourth reading. In the fifth reading, we read the text once again to compare all the themes from the previous reading to the text as a whole, so that a new understanding could be formed.

The steps in the analysis process and the generated themes are exemplified in Table 2. To ensure the rigour of the analysis, all the authors read the final version of the analysis and the themes. In addition, quotations are used to illustrate the findings to show the validity of our interpretations. To try to secure trustworthiness and reduce potential threats to validity, we used the 'trustworthiness' criteria described by Lincoln and Guba (1985): credibility, transferability, dependability and confirmability. Credibility is achieved through open-ended questioning, prolonged engagement with the data and articulation of a detailed description of the methods. Transferability was performed by providing an in-depth, detailed and descriptive analysis of the data and by quoting participants' responses to substantiate the findings. To achieve dependability, the

transcriptions were reviewed several times, and they were checked and coded by the first author and validated by the co-authors. Additional interpretations were arrived at based on consensus among all the authors. Confirmability was obtained by substantiating each emergent theme with rich quotes that were extracted from the participants' responses.

Berger (2015), stated that the position and reflexivity of the qualitative researcher are of paramount importance at all stages of the research process. The researchers' professional background and professional experience may have affected the data collection and analytic procedures. Specifically, the researcher who conducted the interviews was familiar with the 'language' of the research context and could therefore address certain topics or ask follow-up questions during the interviews. This could have influenced both the quantity and quality of the data in a positive manner (i.e. enrichment of the data). However, there is a risk that the researcher might have overestimated the between-participants similarities and consequently overlooked individual differences in experiences; this may have impeded the discovery and construction of new knowledge (Enosh & Ben-Ari, 2016). To avoid this, the researchers maintained a constant sense of awareness about how their preconceived notions may affect the study findings both during the interviews and data analysis.

RESULTS

The five-reading hermeneutic interpretation analysis (See Table 2) resulted in three primary themes. The three primary themes are presented as the following three sub-sections, and the selected quotations from the interviews are illustrated to show the validity of the interpretation of our findings.

After the first month, four participants (P17, P18, P19 and P20) withdrew from the study. All four of them stated clearly that they did not see the need to use Tangible Cup. Their withdrawal is described in detail under the theme 'Reasons not to use'.

Table 2. Summary of themes

Primary themes	Secondary themes	Basic themes
Reasons to use	Experienced good conversations	Willing to open up
		Good at talking
	Motivating factors	Potential friendship
		Hope for more calls
		TUI object - interesting
		Use with family/Little time with family
		Interests-based
		Dating
Reasons not to use	Difficulty in making contact	Called but no answer
		Not answering due to not hearing the device ringing
	Suitability	Passive use
	Experienced bad conversations	Only want to be the listener
		Busy enough – social life
	Withdrawal	Difficult to be logged in at the same time, different schedules
		Bad at talking to strangers
		Too little information about the other users
		Not willing to open up
		Health problems

The mismatch between the attitude and behaviour of older adults using ICT and the design of the technology	Forget easily Usability issues Need motivation	Thought that they had logged out but had not
		Accidentally turned down/switched off the volume
		Misunderstood the use of the coasters (order, search contacts)
		Intuitive – Need instructions, reminders, suggestions
		No ring tone when calling
		No missed call indication
		No battery level indicator on cup attachment
		Less human
		Do not take initiative by themselves
		Affected by other users
		Like follow-up
		Gender difference

Reasons to use

The greatest positive outcome of using Tangible cup is that some participants had good conversations. Together with this primary positive outcome, there are other motivating factors that contribute to the reasons why some participants wanted to use Tangible Cup. These participants faced similar challenges in using Tangible Cup, which are mentioned in the next section. However, they had better experiences, and we describe these in detail in this section.

We noticed that those who were more open were more likely to enjoy the conversations via Tangible Cup. Some of them were already naturally good at talking. Once they managed to talk about more than just the project, they enjoyed the conversations.

> *'I wanted to know what her name was. I said, "Do you mind telling me what your last name is?". I told her mine first, and she told me her name and last name, and what she has been doing, and so on… And she talked a lot about how she was living in a big house, and yes, that kind of everyday thing. And we laughed a bit, because we thought that it was nice that we were both suddenly younger than we were, She was 70 and I was 70 (referring to the age displayed in Tangible Cup)!' (P4)*

Since it was difficult to make contact with the other participants, finally managing to get to talk to each other was especially exciting!

> *'I think it was fun! So great! So nice finally! And then the other lady said, finally, yes now I've succeeded!'(P9)*

Furthermore, we are pleased to see that some of these enjoyable conversations could lead to potential friendships. Due to the difficulty of being online at the same time, some of them even thought of making an appointment with the person they were talking to after their first conversation.

> *'I said, 'is there a suitable time that I can call you? Like a specific time that I can contact you in the evening or during the day'. She's busy during the day, and so am I. So we agreed that if I was going to contact her it should be in the evening, but not after 9, 10…' (P9)*

The hope of receiving more calls might have motivated the participants to use Tangible Cup more. Most of the participants hoped to receive more calls, but for different reasons. Those who just wanted to be the listeners hoped to receive more calls as they wanted to help others who were feeling lonely and wanted to talk.

> *'Yes, I have been logged in all the time. And yes the people have had the chance to call me the whole time if they wanted to, but none of them have. You could say it's a bit disappointing. It would have been nice if someone had called!' (P15)*

While the others who had enjoyed their conversations also hoped for more calls.

'I would like to talk more to (name of P5). I thought that was…. I thought about it afterwards, that it was very pleasant actually. It was also very pleasant to talk to (name of P12)! So then it was like I almost suggested that we could meet (referring to P5).' (P3)

And lastly, the group of passive users (who did not call the others) but who perhaps felt lonely at times, also wished to receive more calls. Although they were disappointed, hoping for more calls was seen as a positive feeling. In future, when Tangible Cup is used by the right user group, it could benefit those in need.

'Yes, it was on every day, but it never made any sound. And when I used it, I sat down here and hoped that I would get to have a conversation, but it never happened.' (P12)

Since Tangible Cup adopts TUI, the interaction between the TUI object and tablet appeared to be intuitive to the participants. All the participants easily grasped the idea of using Tangible Cup. Furthermore, they found the interaction with a real physical object interesting and fun.

'I think the positive thing is the design, absolutely. And it's a bit fun too. It's almost like a board game, where you move the cup here and there. … And once you start using it you think it's easy.' (P3)

In terms of functionalities that can motivate the older adults' use of Tangible Cup, the participants would like to extend the use of Tangible Cup to their family members. Some of them have contact with their children, but they are busy most of the time. Their children use other ICT tools or social media that their parents do not use. Only a few of the participants use social media such as snapchat and Facebook.

'It would be very fine to have something like that as a family contact tool, and also for contacting friends so that you can chat two, three days a week, or something like that. My kids know about this project. They have not commented much. They think it looks interesting, but otherwise nothing else.' (P12)

The older adults are afraid of making mistakes when using social media. Thus, the simplicity of Tangible Cup made them feel safe. Tangible Cup offers no other functionality than just calling and conversing with other people. Although anonymity has been an issue for some of the participants, more than half of them actually thought it was totally fine to talk to strangers. P7 even changed her opinion about talking to strangers. She found it awkward before the study started, but not as difficult by the end of the study. She had nice conversations since the people she had talked to were nice and friendly.

To ensure that the users can have good conversations, we can add an interests-based feature to Tangible Cup. The users can choose to talk to people who have the same interests as they do. The interests can be used as a topic for their conversations as well.

'Maybe it can be based on interests. Like if someone is interested in going to the cinema with me, or if someone wants to go for a walk.' (P5)

Many older adults go to the nearby senior centre where there are other older adults with the same interests. The participants therefore expressed that more older adults could be motivated to use Tangible Cup if it was introduced to them via a senior centre.

'Yes, or tell people about this at a senior centre. Sit there and say that we now need people who don't use a smartphone and don't have a computer or anything. But it's just a case of having it (referring to Tangible Cup) there and of just pressing it and having those cup coasters. And show them visually. Perhaps you will get two or three people that would like to join, who are feeling isolated, who would like to have a friend through ICT.' (P9)

Another possibility that Tangible Cup can offer is dating. P12 who has been single, was actually hoping that he might have a chance to get to know someone new. However, due to the above-mentioned challenges in using Tangible Cup, he did not succeed.

'No, I am only shocked that as a single man, nine women are not interested in calling me.' (P12)

Tangible Cup was not designed as a dating tool. Its aim was to improve older adults' social interaction. However, we were glad to see that it opened up dating opportunities for a few participants. If it had been designed as a dating tool, the older adults might have had second thoughts about using it.

> *'The only negative thing I thought about was men, because I have had bad experiences with men. And I thought that I had no interest in that. When there was a women in the picture I answered them. But I have not called the only man there…. so I have been a bit funny then, think if he, that man called then I would have accepted the call happily! It's funny, it is like on a date you know!' (P9).*

Reasons not to use

During the 12-week pilot study, the biggest challenge all the participants faced was the difficulty of getting other participants to contact them. Many of them had very few conversations even though they actively used the TUI application. The callers attempted to call the others who were logged in to Tangible Cup, but they rarely got an answer. We found out that the main reason for this situation was that some of them did not log out properly from their Tangible Cup, which resulted in the callers calling users who were not actually using the application. When we asked how they logged out, some of them demonstrated this by turning off their tablet's screen. Tangible Cup would still be running in the background as long as it was not logged out by placing the cup attachment on the *log out* coaster. To resolve the situation, we had to manually log some of the participants out from the server side.

> *'They never managed to reach me because I never answered, even though I was always logged in. They must have tried to call me when I wasn't at home. I understood then that I had to log out (Tangible Cup) when I wasn't at home.' (P5)*

We also observed that P12 did not answer incoming calls due to not hearing the ring tone. We saw that he was logged in, so we tried to call him several times. We eventually had to send him a SMS to verify that he was actually present and using Tangible Cup. He informed us that there was no sound when someone called. We noticed that some participants had mistakenly pressed the volume button instead of the power button. This mistake was made by other participants as well.

> *'It was used wrongly and switched off with the big one (the power button). They probably thought they were logged out (by pressing the volume button).' (P1)*

Many of the participants were frustrated by the above situations where incoming calls were not answered. They subsequently gave up calling the logged in participants.

The 'suitability' of the participant is an issue in this study. Many of the participants were actually passive users, which can be explained by a number of reasons. Firstly, some of them were more interested in playing the role of recipient rather than caller. They were willing to answer calls from whoever needed to talk, but rarely took the initiative to call someone.

> *'I'm not in the target group so I'm not seeking contact, but I have tried to use it with the hope that it could help someone to get started (to use Tangible Cup). … I put it on a couple of times during the day to see if anyone is online.' (P14)*

Another type of passive use is due to the busy life of the participants. They had enough to do every day so did not have time to use Tangible Cup. P5 went to a gym, met friends, took care of her grandchildren etc. She was so busy that she did not even remember that she was logged in to Tangible Cup. As a result, her Tangible Cup remained logged in without her being present. Most of the participants are healthy older adults who are fully mobile, so they are active in many different activities. This explains why they were not online at the same time. They were busy at different times of the day.

> *'I have not got into a routine with it, because I never have any idea if I'm going to make contact with other people. The woman I talked to yesterday evening, or yesterday night, is away a lot during the day and at home in the evening. And that is the same as me. I'm not sitting here crying about being alone.' (P4)*

Many of the participants stated that they did not fit into this study, where they were required to talk to strangers. They were not good at talking to people who they did not know. This characteristic made them passive users. P7 usually goes to a senior centre near where she lives. However, she goes there to drink coffee and read. She said that she does not go there to talk to people.

> *'So I found out that talking to strangers is not for me…. I'm not very good at it, and I don't like it either, actually. So I know people through others.' (P7)*

Some participants commented that not knowing more about the other participants restricted their conversations with them. Tangible Cup only displayed the name and age of the participant and where they lived. All the participants were shown as being 70 years old. The age was not displayed 'accurately' in order to make the users as anonymous as possible. Some of the participants disliked this feature. In addition, most of the participants were reserved when it came to talking with the others. They felt they had nothing to talk about apart from this project, as it was the only thing they had in common. None of them opened up to talk about things other than the project.

> *'It's not that easy when you have no idea about them, if they have any education, if they have had a career, you don't know anything. You just talk about the sun shining. Do you understand? It just hangs in mid-air. …I think it's just absolutely hopeless, certainly. … We only talked about the project, what we thought about it. …No matter how nice the people are and they were nice conversations. But it wasn't that… there was none of us who….should you just continue talking on the phone with each other then? Or like what was the point?'(P11)*

P9 who enjoyed using Tangible Cup and had good conversations, commented that other participants could have asked more if they wanted to expand the conversation. She always enjoyed talking to people but it was difficult to get other participants to open up.

> '*Yes, I think I chatter the most, but I have a tendency to talk more so maybe that's why. And then there are many older adults, when they don't know who they're talking to they're very reserved, very cautious, I think.' (P9)*

Four participants withdrew from the study after four weeks of using Tangible Cup, i.e. P17, P18, P19 and P20. They are advanced users of ICT and are adept at using touch screen on their smart phones and tablets. Tangible Cup, which requires using a cup attachment to control the calling app on the tablet, therefore seemed to be more difficult and troublesome for them. The experience of using the cup attachment was described as frustrating by P19, who has many friends overseas who she is in regular contact with. She is active and good at using social media on her smart phone. Hence, she commented that she found using a TUI object, the cup attachment, old-fashioned.

P19 and P20 had health problems that meant they were unable to use Tangible Cup often. During the first four weeks of the study period, P19 travelled overseas and had a serious fall and had to be admitted to hospital. She underwent an operation on her return, and thus did not have much time to use Tangible Cup. P20's health problems meant that she wanted to be alone some days when she was not feeling good. Her children and grandchildren live nearby so there are enough people in her social circle.

Same as the other participants, both P18 and P19 experienced bad conversations. Both of them only had one conversation while testing Tangible Cup, and they both withdrew.

> *'I understand that (name of P18) wanted to talk about her own interests, i.e. knitting, which is not my kind of thing. She wanted to have a nice conversation. I think that (name of P18) and I understand that we didn't have that much to talk to each other about.' (P19)*

All the participants who withdrew expressed that talking to strangers was not suitable for them. This same problem was faced by many of the participants, and has been discussed earlier. P18 mentioned the lack of male participants in the study. During the recruitment process, we found that men were not as interested in trying new ICT tools as women. This made it harder for us to recruit men.

Despite their withdrawal, all four of the participants who withdrew from the study agreed that Tangible Cup would be suitable for people who feel lonely and want to make new friends and talk to someone new.

The mismatch between the attitude and behaviour of older adults using ICT and the design of the technology

Tangible Cup has only been tested in short usability testing sessions during its design and development process (Bong & Chen, 2019). Over this 12-week pilot study, we managed to identify the challenges the participants faced in using Tangible Cup. These challenges were related to their personal characteristics and the ways they used Tangible Cup, as well as the design of Tangible Cup itself. Combining observation with the interviews, some general patterns and behaviours in participants' use of ICT in general were observed. This theme is thus generated by the analysis and concerns factors that might hinder older adults' use of ICT. We generalise these findings and present them as the mismatch between the attitude and behaviour of older adults with respect to using ICT and the technology's design.

Firstly, this user group tends to be forgetful, which also means they get confused easily. This has led to some of them having issues using Tangible Cup, such as not logging out properly and accidentally turning down or switching off the volume on the tablet, which we have discussed in the previous section.

Since they can be forgetful, they like to refer to a user guide. They commented that the user guide is too simple and should include detailed steps. The user guide did not list all the steps from logging in Tangible Cup to logging it out. Instead, we only demonstrated how Tangible cup was used to the participants when we visited them the first time. Although they seemed to understand, we realised during the second visit that many of them were not using Tangible Cup correctly. For instance, some of them misunderstood that the *search contacts* was a group chat function (see Figure 1). They thought that placing the cup attachment there meant they were automatically assigned to a group chat. Others did not remember to place the cup attachment on the *search contacts* coaster after logging in.

> *'It's irritating when I don't manage to get in, and it won't go any further. It stops at this lady (referring to log in screen) and nothing more. It irritates me!' (P9)*

Thus, older adults need clear instructions and guidance when it comes to using ICT. The older adults could always refer to the user guide when they did not remember the steps. P6 did not remember how Tangible Cup worked and always remembered incorrectly that phone numbers were required to call the other participants even though it had been explained to her several times.

> *'No, I think it certainly was just me that didn't manage to understand, and I didn't understand how I could find those phone numbers. No…I'm a bit slow yes….' (P6)*

Some of them also misunderstood that the cup coasters had to be placed in a certain order. The actions can be performed as long as the cup attachment is placed on the right coaster, regardless of the order of the cup coasters.

> *'And sometimes I was a bit impatient. So I put it on calling (referring to call coaster) but I forgot to put in on conversation (referring to search contacts coaster) first. And so I sat down and mixed things up, and it was like "oh". And then I became very irritated, and suddenly slid one of them into another. So I thought, which order should I put them in so that it becomes slightly easier and I can do it a bit faster?' (P13)*

We noticed that many of the participants said that Tangible Cup was easy to use but demonstrated it incorrectly when we asked them to show us how they used it. Thus, it is crucial to make Tangible Cup more intuitive and user-friendly. For example, in addition to the instructions in the user guide, we can include instructions, reminders and/or suggestions inside the app itself. When the expected actions are not being performed by the older adults, the app could prompt guiding messages.

Usability issues are another factor to be considered. The participants found it problematic that there was a ring tone on the recipient's end but not on the caller's end. This made them feel unsure about whether they were doing the right thing when they put the cup attachment on the *call* cup coaster. There was a text indicating that they were calling but no ring tone, and it was thus not intuitive and informative enough.

> *'I think that it's a bit strange when I have moved it (cup attachment) to the call tone (referring to the call coaster), I haven't heard a ring tone, even though there is a telephone behind those I have called (referring to logged in users).' (P16)*

The participants knew they might have missed some incoming calls. However, missed calls were not indicated in Tangible Cup. This is an important feature for the users, because it could indicate who was interested in talking to them and thus possibly motivate them to call them back.

> *'It should be developed in a way that if someone tries to make contact with somebody else, it sends a message that the person has called. So that you can see when you log in that someone has tried to contact you. Then I can try to contact the person back….and there should be a function where you can leave a message that you have tried to call but there was no answer, so that you understand that it work.'(P6)*

In addition, there was no battery level and charging indication shown on the cup attachment. The cup attachment can last for 7 to 8 hours once it is fully charged and we have informed the participants about this in a written instruction. Some participants had problems charging the cup attachment due to the charging port being too loose. In addition to this, many of them were unsure if the cup attachment was charging or fully charged because, unlike the tablet, there was no indication of battery level.

> *'But then I had everything on the floor, right…because it was meant to be in the charging port. Because I didn't know how long it was supposed to charge, I had no idea. So I wish that the cup attachment could be…in a way I could tell when it was charging. I was missing that.' (P7)*

Some of them also felt that Tangible Cup did not offer them human interaction. Although Tangible Cup enabled them to talk to a real human being, some of them preferred face-to-face conversations, while others wanted to meet up in person at a café or senior centre for example.

> *'I read that it was supposed to help people not to feel lonely, but you don't feel less lonely by sitting and looking at this thing. It's human contact that counts…. Away from your home!' (P1)*

This attitude discouraged them from using Tangible Cup and, in the future, we hope to change their attitude to using ICT. Using ICT to make new friends can be a good start that leads to meeting each other in person.

> *'We talked about the ideal aspect of this, that you shouldn't sit alone and feel isolated, you should make friends! And I'm interested in that point. So I see that this is a good idea, if it can lead to the elderly getting up from their chairs. Maybe meeting someone, or talking to someone in the evening.' (P9)*

The participants did not always take the initiative to use Tangible Cup, or to make the first move and call the other logged in users. The older adults need motivation when it comes to using ICT, and one of their main sources of motivation is the other users. These reasons not to use demonstrated how some of the participants were demotivated by the use of Tangible Cup. They thus started to give it up, and as more and more of them gave it up, fewer and fewer participants were online. This resulted in demotivating those who were initially active.

> *'Uncertainty about how I should do it when I didn't make any contact. The fact that I didn't make any contact made me lose confidence and faith in it.' (P1)*

In addition, the participants liked to be followed up. P6 had not started using Tangible cup when we visited her during the mid-study.

> *'I haven't used it because I have yet to figure out which cup coasters I should put it (the cup attachment) on. So it was nice that you could show me again.' (P6)*

She actually wanted us to visit her more often so that we could follow her up in terms of her use of Tangible Cup. It can be argued that in addition to older ICT users requiring motivation, many of them also need regular follow-up. A reminder and suggestion feature can be added to Tangible Cup in the future. Older people can thus receive reminders and suggestions to call the other users, since they do not generally take the initiative on their own.

Last but not least, we notice a gender difference in terms of the attitude and behaviour of older adults using ICT. Most of the older men wanted to be seen as tough and independent, and thus denied that they needed ICT to improve their social lives. This resulted in our recruitment process not succeeding in recruiting more male participants.

> *'I was so disappointed, especially in the men at the centre (referring to the senior centre), they never join anything! And then they say "there are so many women at the training parties (referring to activities at the senior centre) that I feel like I am lost (not connected)". So there is a very big difference between the genders. And you see that when we have these social evenings with dinners and things like that. There might be around 40 ladies and 3 men, at a rough estimate. And then we dance with each other, because there is live music and they have set it up to be a bit fun. …but why can't these men stand up and do a waltz or something like that? I say, listen you're not a poor walker, why don't you take a lady up for a dance?'(P13)*

DISCUSSION

To the best of our knowledge, this study is the first to investigate older adults' experience of using TUI for their social interaction and quality of life. The findings show that the use of Tangible Cup had both positive and negative impacts on the participants' social interaction. Several users expressed their enjoyment of using Tangible Cup. A total of six participants would consider further developing friendships with the call recipients they had talked to. This is a clear indication that Tangible Cup had an impact on their social interaction. They told us that the conversations went well when both the caller and the recipient opened up and talked about more personal matters. Some of them would even consider meeting each other in person. As found in a study using an accessible iPad-based app to support older adults' asynchronous communication with family and friends (Barbosa Neves, Franz, Judges, Beermann, & Baecker, 2019), the use of Tangible Cup can open up possibilities for improving older adults' social interaction.

The positive impacts on these participants' social interaction are believed to have some positive impacts on their quality of life as well. Previous studies have shown that the social aspect plays an important role in older adults' quality of life (Bowling, 2009; Bowling, Banister, Sutton, Evans, & Windsor, 2002; Gerino et al., 2017). When older adults have better social interaction and social relationships, they tend to feel more positive and therefore, have better quality of life (Bergland et al., 2016; Boz & Karatas, 2015; Corner et al., 2006; Gustafson et al., 2015; Scocco & Nassuato, 2017; Theeke & Mallow, 2013).

However, the use of Tangible Cup did not go as smoothly as expected due to some challenges that occurred during the 12-week study. Although Tangible Cup has been tested throughout the design and development process (Bong & Chen, 2019), this study is the first time Tangible Cup was used and tested with all its functionalities over a long period of time at the participants' homes, which is the most natural setting for them to use ICT without any supervision. Several usability issues and unforeseen user behaviour were identified that resulted in challenges in using Tangible Cup.

Heinz et al. (2013) investigated older adults' perception of technology and 'frustrations, limitations and usability concerns' emerged as one of their main themes. Our main theme 'the mismatch between the attitude and behaviour of older adults using ICT and the design of the technology' illustrates a similar concern. The participants in a study by Heinz et al. (2013) disliked that the technology might lead to reducing human contact; while the participants commented that the communication through Tangible Cup was slightly 'less-human'. It is important to teach older adults that using ICT is intended to enhance their social interaction with other human beings, and not to replace it. This could motivate them to accept and use ICT.

Barbosa Neves et al. (2019) identified five feasibility elements to be considered in an accessible app to enhance older adults' social connectedness. Our findings supplement some of these feasibility elements. Firstly, 'the active involvement of one tie' was considered important when the older participants needed to learn and use Tangible Cup. Some of them mentioned that they would use Tangible Cup more if someone they already knew was also using it. According to Wood and Bandura (1989), the behaviour of an individual relies on his or her environment, cognitive and other personal factors. In this context, the other users using Tangible Cup constitute the individual's environment. We have found that older adults need motivation from their surroundings when it comes to using ICT, and one of their main sources of motivation is other users. The participants would also use it more actively if they were able to make more new friends through the use of Tangible Cup. This is another feasibility element, 'perceived usefulness and functionality' that influenced the ways the participants used their Tangible Cup.

Our 12-week pilot study pointed out the importance of follow-up and feedback to older adults. Vaportzis, Giatsi Clausen, and Gow (2017) investigated older adults' use of tablets and found that a lack of instructions and guidance was a major barrier to older adults using technologies and tablets. Our findings supplement this study. Most of the participants did not always remember the steps and right way to use Tangible Cup. They liked us visiting them often and demonstrating the use of Tangible Cup to them. It is worth mentioning that some of the participants received more visits from us due to the use of Tangible Cup. This may have contributed to their social interaction and relationships. Dickinson and Gregor (2006) argue the same in their study, i.e. that the effects of training/support may have contributed to the well-being of older adults, and not the use of a computer.

The participants' use of Tangible Cup has revealed some general characteristics in older adults using ICT, i.e. they tend to forget things easily and need motivation. When designing ICT for older adults, it is important to pay attention to these characteristics and address their needs accordingly. As pointed out by Hallewell Haslwanter, Fitzpatrick, and Miesenberger (2018), older adults are very diverse. Our findings indicate the same, and there is no single solution for older adults' use of ICT. In their systematic review, Chen and Schulz (2016) propose identifying older adults whose social isolation can be reduced by using ICT. On the background of this 12-week intervention involving 20 older participants using Tangible Cup, we propose characteristics in older adults for whom TUI is most suitable, and what kind of TUI design is appropriate for them.

Target user group

All of the participants in this study are average and advanced ICT users, and our results show that they were not the target user group for using Tangible Cup. As suggested by most of the participants, ***older adults with low or no ICT literacy*** should be the main target user group. ICT literacy is associated with many factors. A study conducted by Olsson, Samuelsson, and Viscovi (2019) including 796 Swedish respondents aged 65 to 85 shows that age has a negative correlation with ICT skills. Older adults need more time and effort to learn new technologies. While our application is inspired by a cup, Davidoff et al. (2005) used a book as a TUI object for older adults to send messages. Similar to our findings, their results suggest that TUI can appear more intuitive and familiar to older adults because it uses an everyday physical object as part of the user interface. This can help older adults with low ICT skills to learn new technologies because they can easily relate the new technologies to everyday life.

Some ***older adults face challenges in using tablet devices***. Previous studies investigating older adults' use of tablets highlighted some negative features of tablets (Barnard, Bradley, Hodgson, & Lloyd, 2013; Vaportzis et al., 2017) and our findings support these studies. Some older adults have problems understanding touch screen technology and the user interfaces in tablets compared to laptops and personal computers (UISEL, 2015). Vaportzis et al. (2017) revealed in their study that older adults found the buttons on a tablet

cumbersome. The participants in our study made the same comment. Without labels and names, the participants made mistakes and confused the power button for the volume button.

TUI can appear to be more intuitive than interface elements on tablets and touch screens. For older adults who have ***restricted physical abilities***, for instance weaker muscle control in fingers, touch screen buttons and icons can be problematic, especially when they are small (Xiong & Muraki, 2016). Instead of interacting with small buttons and icons on a tablet, TUI provides a bigger physical interface for older adults to interact with. Some of the participants commented that the use of Tangible Cup can help older adults with restricted physical abilities to control the tablet better.

TUI designs

After this 12-week study, some usability issues identified that should be addressed to resolve the mismatches, are presented in the results section. By addressing these issues, TUI designs are also developed to be more suitable for the older adults. Through the process of designing Tangible Cup, a list of lessons has been learned about what to consider when designing TUI for older adults, i.e. ***using familiar physical objects, integrating TUI into their daily life, having minimal functionality, avoiding crowded interfaces, considering older adults' physical abilities, providing necessary instructions and making the use of TUI practical to older adults*** (Bong & Chen, 2019). Some of the lessons learned are applicable in addressing the usability issues identified in this study and improving Tangible Cup in the future. For instance, alert message can be prompted on the tablet when the user accidentally turns down or switches off the volume (providing necessary instructions) and the cup attachment could have a battery level indicator (making the use of TUI practical to older adults).

During the 12-week pilot study, we observed two important features that may be useful to older TUI users. The first is ***automation***. Some older adults suffer from age-related memory decline and tend to forget things (Craik, 1994). Automation has been used in other ICT tools to assist older adults, such as tele-homecare (Nourizadeh, Deroussent, Song, & Thomesse, 2009). Automating a feature such as automatic log out of users after a long period of inactivity, can eliminate the chance of the users forgetting and/or not logging out properly. Some of the participants did not log out by placing the cup attachment on the *log out* coaster. They thought that they could simply log out by pressing the power button and turning off the screen. However, the app was actually still running in the background and their status was shown as logged in to the other users. This resulted in callers not receiving answers to calls, which made them frustrated.

Some of the participants felt that too little information was displayed about the other users in the app, while others appreciated that minimal information was shared and that they could then ask more personal questions in the conversations. Such information can be customised on the app, so that the users can decide how much they want to see, and how much they want the others to see. ***Customisation*** can address the different needs of diverse older adults (Camarinha-Matos, Afsarmanesh, Ferrada, Oliveira, & Rosas, 2013), and this applies to TUI design as well. According to the participants, Tangible Cup has to be more accessible and intuitive to adapt to older adults' use of TUI. Customisation shall not be limited to the design of TUI, but also cover the use of TUI. Chen and Schulz (2016) suggested that customised training should be organised for older adults when ICT is used to address their social isolation problem. Older adults can benefit from customised training material, settings, procedures and the instructor customising his/her style and attitude. Customised training and follow-up are necessary to ensure the maximum impact of TUI on the social interaction of older adults.

Strengths and limitations

To assure the transferability and generalisability of our qualitative data, we presented rich and detailed descriptions of the participants' 12-week experiences of using Tangible Cup on their social interaction and quality of life, as suggested by Lincoln and Guba (1985). Despite the strengths in the presented results, the

main limitation of this study is clear. Our intervention period of 12 weeks could be too short. According to the study by Woodward et al. (2011), which examined the relationship between providing ICT-related training to older adults and their ICT use, the older adults' ICT use and the number of people in their social network increased over time. The impacts of using Tangible Cup on the participants' social interaction and quality of life could be more significant if we had conducted this pilot study over a longer period.

In addition, with only 20 participants, it was very hard for them to be online at the same time. Although we might have achieved data saturation (Guest et al., 2006; Ness, 2015), the concept of 'information power' (Kirsti Malterud, Siersma, & Guassora, 2016) was neglected. 'Information power' relies on (a) the aim of the study, (b) sample specificity, (c) use of established theory, (d) quality of dialogue, and (e) analysis strategy. Our study did not have enough sample specificity. Prior to recruiting the participants, we had no knowledge of their ICT skills and social life. As discussed earlier in this paper, the participants had above average ICT skills for older adults. Tangible Cup is not suitable for this group of older adults. Most of the participants reported an active social life so they had little time to use Tangible Cup. Each group originally started with 10 users. After four weeks, two users from each group withdrew from the study. After the mid-study visit, the remaining 8 users in each group were told to use Tangible Cup during certain time slots. This strategy helped to a certain extent as most of them finally managed to talk to someone using Tangible Cup.

Same as the study investigating older adults' use of tablets (Vaportzis et al., 2017), the majority of the participants are women. Out of the 20 participants who we managed to recruit, only two were men. The original inclusion criteria was that the participant had to live alone. However, since so few older men were interested in joining our study, we had to include one man who was still living with his wife. One of the reasons for this could be that more women tend to feel lonely and therefore agree to participate in such studies (Chen & Schulz, 2016). Vaportzis et al. (2017) commented that women might be more keen to help and participate in such research studies, which is also our experience. Some participants considered Tangible Cup a potential platform for making new friends of the opposite gender. The significant imbalance in the number of each gender could lead to some participants losing their motivation to use the application. P18 even stated this as one of the reasons why she withdrew from the study.

The authors of this study are researchers working on human-computer interaction and health sciences. Thus, our study design, data collection, analysis and interpretation have been influenced by our backgrounds and preconceptions. A strength of this study is that the authors discussed and reflected on this throughout the research process (Polit & Beck, 2017). Our paper might be of importance when customising education for health, social, technological professionals along with those providing health services for older people. The study might contribute important knowledge to facilitating older people's use of TUI to enhance their social interaction and quality of life, as well as contributing to enhancing a broader understanding of older adults' everyday life situation.

CONCLUSION

Our pilot study explores the use of a TUI application, Tangible Cup, by 20 older adults over 12 weeks with respect to quality of life and social interaction. The findings indicate that those who were motivated to use Tangible Cup were more open in their conversations and had positive experiences of having good conversations.

The challenges of using Tangible Cup were related to the difficulty of making contact with other users as well as the use and design of Tangible Cup, which were not suitable for the participants in our study. Notwithstanding the study's limitations and the participants' challenges in using Tangible Cup, all the participants agreed that Tangible Cup had the potential for further development and use by a certain target user group. Based on the results, we first recommend the characteristics of older adults who could benefit more from using TUI. Older adults who have no or low ICT literacy and struggle with touch screen technology

are the target user group for TUI. We then propose TUI designs that are appropriate for older target users of TUI. Automation and customisation are helpful designs that could enhance older adults' experience of using TUI. This pilot study provides useful information about making TUI a more intuitive and usable user interface for older adults. TUI's ability to contribute to improving older adults' social interaction and quality of life as a whole is thus promising. In terms of the implications of the study, the findings may contribute to facilitating the delineation of improved strategies, which can inform policy makers, educators, clinicians, future researchers and older adults. In the future, on the basis of the feedback received, we hope to improve Tangible Cup and reach out to the target user group that will benefit from using TUI.

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