MEET THE PEER AND THE COOK

DESIGN AND EVALUATION OF PERSUASIVE EMBODIED CONVERSATIONAL AGENTS TO SUPPORT HEALTHY AGEING

LEAN L. KRAMER

Propositions

1. Co-creation does not necessarily lead to more useful eHealth tools.
   (this thesis)

2. Future eHealth interventions should be focused on high-frequent and short-term engagement with the eHealth tool.
   (this thesis)

3. Researchers should personally verify whether participants understand the informed consent form.

4. It is more important to investigate mechanisms driving interventions' effectiveness than demonstrating the effectiveness of the intervention itself.

5. Citizens with concerns about the privacy handling of data in covid-19 apps should not use Facebook.

6. The government will only be successful in improving population health if citizens do not feel harmed in their feelings of autonomy.

Propositions belonging to the thesis, entitled

Meet the Peer and the Cook:
Design and evaluation of persuasive
Embodied Conversational Agents
to support healthy ageing

Lean L. Kramer
Wageningen, 26 November 2021

Meet the Peer and the Cook

Design and evaluation of persuasive Embodied Conversational Agents to support healthy ageing

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Meet the Peer and the Cook

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Lean L. Kramer

Thesis

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Chapter 1

General introduction

Imagine Mrs. Smit. She is 84 years old. Mrs. Smit enjoys walking despite the fact that she uses a walker. She has noticed that the distance that she covers is becoming less. She went shopping three days ago, and so the fridge is still reasonably full. Enough to cook for herself tonight. She feels cooking is increasingly becoming a fuss. All those actions, those heavy pans are hard to lift, and draining rice is no longer as easy as it once was. She prefers to eat French fries at the snack bar beside the apartment. Sometimes, she finds herself thinking: "If someone came over to join me for dinner, that would make things a lot cozier."

The PACO project was initiated to learn how we should design and evaluate Embodied Conversational Agents (ECAs) for persuading people towards health behavior change. The PACO service can engage people like Mrs. Smit, a community-dwelling older adult, in dialogue with ECAs about her habits, using techniques such as action planning, self-monitoring, and social facilitation to change her eating behavior.

This case was used for an assignment in the co-design study (Chapter 4.)

Background

Healthy ageing

"Healthy ageing is the process of developing and maintaining the functional ability that enables well-being in older age." [1]

Globally, the proportion of older people relative to younger people in the population is increasing rapidly – to such an extent that the ageing of the global population is the most important medical and social demographic problem worldwide, according to the World Health Organization [2]. In 2020, the global population aged 60 years and over was just over 1 billion people, representing 13.5% of the world's population. That number is 2.5 times greater than in 1980 and is projected to reach nearly 2.1 billion by 2050 [3]. An important consequence is the increase in the utilization of, and expenditure on, global health services [4]. In the Netherlands for instance, older adults form about 20% of the total population while accounting for approximately 80% of total healthcare expenditure [5, 6]. Apart from healthcare utilization and expenditure, adding more years to life can be a mixed blessing for individuals if it is not accompanied by more life added to those years.

A healthy lifestyle is related to subjective well-being. Older adults who eat healthily, do not smoke, and are at least moderately active are more likely to experience higher life satisfaction [7]. This relationship also works the other way around. Unhealthy lifestyle behaviors have the strongest influence on the burden of disease [8], and most causes of death can even be linked to lifestyle behaviors, at least in developed countries [9]. However, knowing this does not make people change their behavior. Regarding the current nutritional status of community-dwelling older adults for example, a majority appear overweight and suffer from undernutrition, or both [10]. They consume, for instance, more unhealthy saturated fatty acids and more salt than recommended and fewer wholewheat products, fruit, and fish than recommended [11]. However, an unhealthy lifestyle is not the only important issue influencing older adults' well-being.

Loneliness is emerging as one of the most important health issues facing older people and is even more urgent now, as the likelihood of loneliness has increased during the COVID-19 pandemic [12]. Loneliness has been defined as ''the discrepancy between an individual's desired and achieved levels of social relationships" [13]. In the Netherlands, more than half of all older adults indicate that they experience loneliness, a percentage that is even higher among people without a partner [14]. Loneliness is comparable to well-established risk factors for mortality, such as tobacco use and alcohol consumption [15, 16]. Furthermore, loneliness negatively influences older adults' well-being and is associated with unhealthy lifestyle behaviors. Research shows, for example, that the best diet quality is associated with eating at the table as opposed to eating meals on one's lap. However, many older adults, especially after losing their significant other, often find themselves eating alone, with a meal on their lap [17]. It is also precisely this group of solitary community-dwelling older adults that is often overlooked in health interventions [8].

Promoting health among older adults can contribute to an increase in healthy life years and life expectancy [18]. There is some evidence, for example, that nutrition education interventions can improve nutrition-related outcomes in community-dwelling older people [19]. However, the strength of currently available evidence is weak; the studies have methodological limitations, including a small sample size and high attrition rates [19]. Interventions that focus on loneliness are, for example, the use of therapeutic pet robotics such as PARO, initiatives that facilitate

eating together, or social skill programs. However, an umbrella review from 2020 concludes that their overall effect is limited [20]. Most health interventions take a one-size-fits-all approach, meaning that the intervention is not adjusted to the requirements of the target group. This approach is proven to be ineffective and insufficient for healthy ageing [20–22]. Moreover, the limited understanding of the effective components of health interventions hinders the possibility to improve them [20–22]. Hence, there is an urgent need to develop and study the working mechanisms of interventions concerning two urgent health issues among community-dwelling older adults: nutrition and loneliness.

eHealth and older adults

It is still commonly believed that older adults often do not, and are unable to, use technology. Hence, when interventions for older adults are being considered, technology is most likely not the first avenue that comes to mind. However, times are changing rapidly, and the internet is more and more intertwined with everyday tasks – for example banking, completing tax returns, or keeping in touch with family members. Nowadays, it is rather difficult not to use technology. This trend of increased technology use can also be seen among older adults. Back in 2012, over 25% of older adults between 65 and 75 had never used the internet. In 2019, this number had reduced to 8.7%. Nowadays, almost all older adults have internet access (94.6%), and over three-quarters use the internet daily [23]. With all the advances in technology, and more and more older adults becoming familiar with them during the COVID-19 pandemic to keep in touch with their friends and family members, it is most likely that internet usage will only keep increasing. Therefore, the use of eHealth services will probably increase also.

eHealth includes "health services and information delivered or enhanced through the internet and related technologies" [24]. These services are used in almost every part of the health domain, from health education to screening and from self-management to support with everyday tasks. Common arguments for using the internet to deliver health interventions include the cost-effectiveness in terms of resources and the increasing convenience for users and health services [25]. Furthermore, eHealth can help overcome users' isolation, provide timely information, reduce stigma, and increase both user and supplier control of the intervention [25].

Health apps and other eHealth services can offer health benefits, enhance the lives of older adults, and support ageing in place [26–28]. Nonetheless, the application of eHealth tools in health promotion among older adults is largely unexplored [29]. eHealth services developed for older adults often target one specific health behavior and are designed for the general adult population [29]. More specifically, there is a lack of evidence about interventions that target both lifestyle and loneliness [30]; and, if these interventions have been developed, they are often not effective in promoting users' health or well-being [30]. A systematic review from 2021 shows, for example, that there are only two eHealth interventions for older adults that target both loneliness and nutrition [31]. However, they are both still in the piloting phase and have not provided any evidence of their effectiveness or working mechanisms [32, 33]. Regarding the currently available health apps, it is known that they do not integrate the needs of older people and do not take account of their low health literacy and chronic conditions [34]. Hence, it is not surprising that older adults make almost no use of health apps, and, if they do, they are not engaged with the respective health behavior [34].

ECAs

The ECA is a specific eHealth technology that can improve users' level of engagement. ECAs – also known as relational agents or virtual agents – are defined as "interactive, animated computer characters that simulate face-to-face counseling" [35]. They often take the form of virtual persons and are accompanied by a scripted chat functionality. An example is 'Sylvia', which can be seen in Figure 1 [36]. Sylvia aims to counter frailty by offering older adults training modules in the domains of healthy nutrition and physical and cognitive training. Studies with older adults show high ratings for ECA acceptance, enjoyment, and usability [36–40]. However, evidence regarding ECAs' effectiveness and working mechanisms is still limited, as it is an emerging field and most studies have focused on usability and user acceptance [41]. Thus, although ECAs show great potential for addressing health behavior change in a persuasive manner in our target group, they are not yet designed or evaluated in a way that makes it possible to achieve this potential.

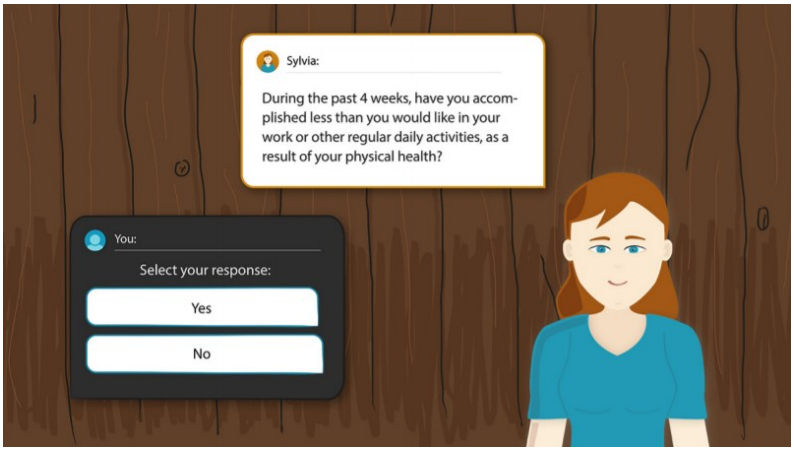

Figure 1: Example of an ECA [36].

Design and evaluation

Regarding eHealth interventions, there are ample examples of technologies that are not used by the target group, because there are too many usability issues and users are not engaged, or the technology is very well designed but usage does not lead to actual behavior change [42]. Therefore, it is interesting to explore how eHealth interventions are developed in different fields and what the consequences are.

In the field of behavior change, interventions are often developed by using behavioral theories, such as the Theory of Planned Behavior [43] or the Self-Determination Theory, using comprehensive development methods such as Intervention Mapping [44] or the Behaviour Change Wheel [45]. Another overview widely used is Michie et al.'s [46] behavior change taxonomy, a theory-linked taxonomy of generally applicable behavior change techniques (BCTs). Their emphasis is on understanding the process of behavior change. Hence, the evaluation is often focused on health effects, ideally measured via a randomized controlled trial. These interventions frequently have a strong behavior change component. However, an eHealth intervention will not be able to change the behavior, knowledge, or motivation of its users successfully if not all available elements are

used, usage stops after a period of time, or the intervention is not used at all. Unfortunately, these are the main problems of eHealth interventions [47–50]. Often, both the extent of usage and the user experience, together defined as engagement, are insufficient [51]. Hence, the combination of a strong behavior change component with a weak user interface is likely to result in an ineffective intervention [42].

Here, the field of human–computer interaction research comes into play. The emphasis is often on developing strong user interfaces, using principles like discoverability and affordances and applying frameworks and theories like the Agile Method [52] and Value-Sensitive Design [53]. Another well-known model that provides an overview of persuasive design principles has been developed by Oinas-Kukkonen and Harjumaa: the Persuasive System Design (PSD) model [54]. Examples of these principles are tailoring, self-monitoring, social facilitation, and trustworthiness of the technology. The technology is often tested with users via usability testing methods. When it is evaluated, its users' usage or engagement level often determines its success.

eHealth interventions that target users' health behavior are complex [55]. However, for such interventions to be successful, it is necessary to deal with this complexity by adopting an interdisciplinary approach. This is advocated, for example, in the Centre for eHealth and Wellbeing Research (CeHRes) Roadmap [56]. The roadmap is a guideline for designing, implementing, and evaluating eHealth interventions, based on activities, models, frameworks, and methods derived from persuasive design, participatory development, human-centered design, and business modelling. However, current research on eHealth interventions that target users' health behaviors is carried out in disparate fields, with a different approach in each of these fields [55].

Aim and outline of the thesis

This dissertation aims to provide insight into how to design and evaluate ECAs that support healthy living. In particular, the focus is on solitary community-dwelling older adults, with the aim of supporting them with healthy ageing by improving their eating behavior and reducing loneliness. The objective is to gain fundamental insights into the acceptance, working mechanisms, and persuasiveness of ECAs for eHealth. An overview of the research questions and the interdisciplinary methods used can be found in Figure 2.

The studies in this thesis are embedded in the three-year PACO project, funded by The Netherlands Association for Health Research and Development (ZonMw). The PACO project is being carried out by an interdisciplinary team consisting of Wageningen University & Research, Roessingh Research and Development, the National Foundation for the Elderly, and WAAG. PACO is an acronym for the research question: How to design Persuasive virtual Agents for Coaching Older-adults towards dietary behavior change?

During the development process, the CeHRes Roadmap phases are followed. The framework consists of five phases: contextual inquiry, value specification, design, operationalization, and summative evaluation. Each phase roughly represents a chapter in this thesis, with the exception of the operationalization, which, given the fundamental nature of that project, is outside its scope. The stakeholder analysis (part of the contextual inquiry and value specification), the usability study (part of the design), and the pilot evaluation (part of the formative evaluation) are not part of this thesis. Nonetheless, these studies, performed by MSc students, contributed to the project.

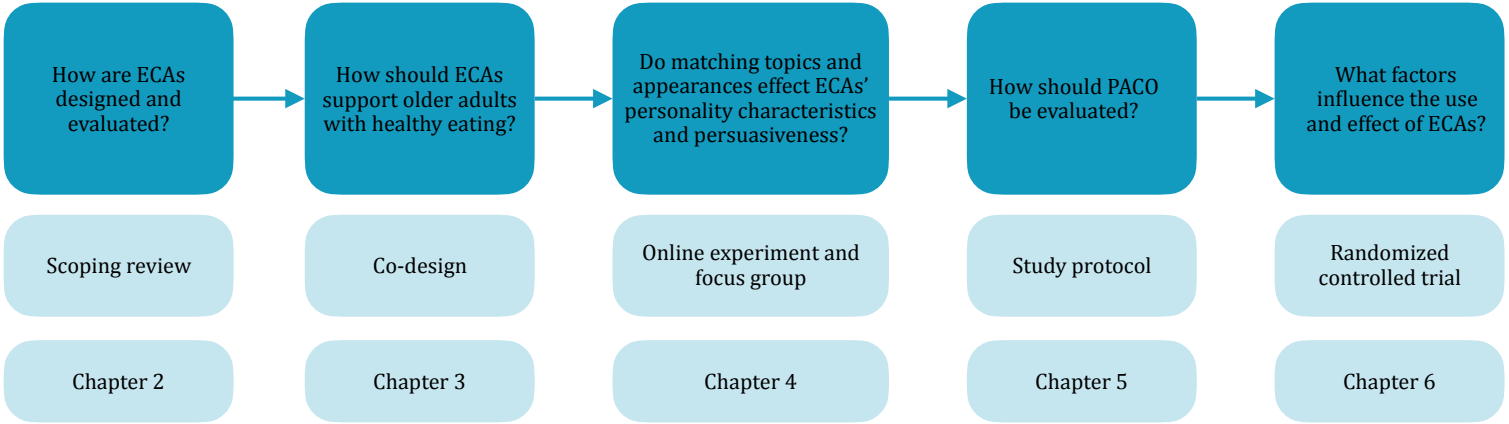

Figure 2: Schematic overview of research questions and methods.

Outline of the thesis

In Chapter 2, the current practices in designing and evaluating ECAs in the health domain are explored, and an overview is provided of their efficacy and use-related outcomes. In Chapter 3, a co-creation process with older adults is described, and the outcome of this process is used to inform both the content and the appearance of the ECA. This study adds knowledge on the meaning of healthy eating, as well as on specific barriers to, and opportunities for, using an ECA to give advice to the target group. The design of the ECA is further discussed in Chapter 4, which describes an online experiment with the goal of identifying the effect of a match between the ECA and the health topic. Once the design was finalized and a usability study was conducted, a study protocol was established to evaluate the use and effect of PACO. In addition, two conceptual models were created – one for use and one for effect. The protocol and an extensive description of PACO and the design process are presented in Chapter 5. The results of the summative evaluation, and the verification of the conceptual models, are described in Chapter 6. The last chapter, Chapter 7, summarizes the main conclusions of this thesis, the results are placed in a broader perspective, the limitations of the research are discussed, and suggestions for future directions are provided.

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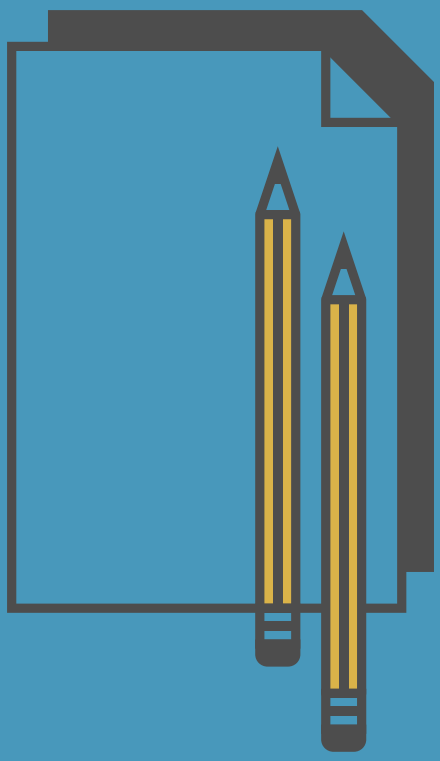

Chapter 2

Developing embodied conversational agents for coaching people in a healthy lifestyle: Scoping review

Abstract

Background: Embodied conversational agents (ECAs) are animated computer characters that simulate face-to-face counseling. Owing to their capacity to establish and maintain an empathic relationship, they are deemed to be a promising tool for starting and maintaining a healthy lifestyle.

Objective: This review aimed to identify the current practices in designing and evaluating ECAs for coaching people in a healthy lifestyle and provide an overview of their efficacy (on behavioral, knowledge, and motivational parameters) and use (on usability, usage, and user satisfaction parameters).

Methods: We used the Arksey and O'Malley framework to conduct a scoping review. PsycINFO, Medical Literature Analysis and Retrieval System Online, and Scopus were searched with a combination of terms related to ECA and lifestyle. Initially, 1789 unique studies were identified; 20 studies were included.

Results: Most often, ECAs targeted physical activity (n=16) and had the appearance of a middle-aged African American woman (n=13). Multiple behavior change techniques (median=3) and theories or principles (median=3) were applied, but their interpretation and application were usually not reported. ECAs seemed to be designed for the end user rather than with the end user and stakeholders were usually not involved. A total of 7 out of 15 studies reported better efficacy outcomes for the intervention group, and 5 out of 8 studies reported better use-related outcomes, as compared with the control group.

Conclusions: ECAs are a promising tool for persuasive communication in the health domain. This review provided valuable insights into the current developmental processes, and it recommends the use of human-centered, stakeholder-inclusive design approaches, along with reporting on the design activities in a systematic and comprehensive manner. The gaps in knowledge were identified on the working mechanisms of intervention components and the right timing and frequency of coaching.

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Introduction

Background

Public health would substantially improve if a large number of people adopted a healthy lifestyle, encompassing among others, ample physical activity, and healthy diets [1]. To initiate or coach such change, embodied conversational agents (ECAs) can be a valuable tool. ECAs can be defined as "more or less autonomous and intelligent software entities with an embodiment used to communicate with the user" [2]. Examples include those given in Figure 1; From left to right: Laura [3], Gabby [4], and an anonymous octopus [5]. An example of an early ECA is Laura [3]. Laura interacts daily with users to motivate them to be more physically active. She uses several relational behaviors, such as social dialogue, feedback, humor, facial expressions, and body language. Through these behaviors, users establish and maintain a meaningful relationship [3]. What makes ECAs unique for coaching people with respect to their health is this capacity of establishing and maintaining an empathic relationship [3], a relationship characteristic proven to be the most crucial factor for successful lifestyle coaching [6]. In addition, ECAs are available 24×7. Consequently, they can offer empathic support when it matters most: immediately before or after specific behavior, which maximizes impact [7].

Figure 1: Example of embodied conversational agents.

Despite the promising role ECAs can play in coaching people for a healthy lifestyle, literature that discusses how to develop them and demonstrates their effectiveness is scarce. A review by Provoost et al [8] provides some insight into the developmental processes and evidence base of ECAs for coaching people with mental disorders. They suggest that the more rigorous studies put little emphasis on design and that evidence on clinical effectiveness remained sparse [8]. In the educational context, Johnson and Lester [9] state that there is a significant body of experience and research findings related to pedagogical agents. However, similar to the health context, many questions remain about when pedagogical agents are most effective and how they should be designed and used to

maximize effectiveness. Literature on development and effectiveness is essential to create ECAs that can have a high level of impact and uptake, a problem with which electronic health (eHealth) interventions constantly struggle [10]. The cause for this low impact and uptake is often attributed to a misfit among technological, human, and contextual factors during development [11, 12]. Different authors have therefore recommended to apply a human-centered and stakeholder-inclusive design approach, as well as to incorporate persuasive design features in the technology [11, 13, 14].

Objectives

This scoping review identifies the current developmental practices of ECAs for coaching people in a healthy lifestyle, and it provides an overview of their efficacy and use-related outcomes. For researchers, this review provides an overview of the potential ECAs have to change people's lifestyle and identifies the most urgent research questions related to this domain. For practitioners, the review will lead to actionable advice for devising a development trajectory for this type of ECAs.

Methods

Study Design

The Arksey and O'Malley framework for scoping reviews [15] was adopted, which distinguishes 5 different stages: (1) identifying the research question, (2) identifying relevant studies, (3) selecting studies, (4) charting the data, and (5) collating, summarizing, and reporting the results.

Identifying the Research Question

The research question was identified from a preliminary scan of the literature, which showed a lack of insight into and description of best practices regarding the current development processes. The question that will be answered is as follows: *How are ECAs for coaching people in a healthy lifestyle designed and evaluated?*

Identifying Relevant Studies

To identify relevant studies, a data logbook was created, comprising specific instructions, a plan, a term list, and a data-charting form. The databases used to locate the relevant literature were as follows: PsycINFO, because of its comprehensive library of psychological science; Medical Literature Analysis and Retrieval System Online, because of its wide coverage of scientific journals in the health domain; and Scopus, because of its multidisciplinary scope. The databases were searched for peer-reviewed journal articles written in English, with a combination of terms related to ECA and lifestyle. The keywords were identified based on a preliminary literature scan and in consultation with a research librarian to

obtain a comprehensive list of potential sources (see Supplementary materials 2.1). In addition, we applied the snowball method.

Study Selection

Inclusion criteria were implemented by selecting different options and limits during the search (see Supplementary materials 2.1). The results of the search query were uploaded into the EndNote reference manager (Thomson Reuters) and independently assessed by 2 reviewers (LK and StS) to decide on their inclusion based on title, abstract, and full text. Conflicts between the 2 reviewers were identified after each step independently; arguments were formulated per study and then discussed and resolved. This process was documented in the logbook. To find relevant studies that describe an intervention with an ECA in the healthy lifestyle domain, the following exclusion criteria were applied: (1) there is no report on primary data, (2) there is no intervention, (3) the intervention does not include an ECA (a "more or less autonomous and intelligent software entities with an embodiment used to communicate with the user") [2], and (4) the ECA is not used in a lifestyle health behavior context (eg, tobacco use, physical (in)activity, alcohol consumption, and diet) [4].

Charting the Data and Collating and Summarizing the Results

Data from the selected studies were charted independently by 2 reviewers (LK and BM). The following categories were a part of the data-charting form: (1) article information, (2) study information, (3) general description of an ECA, (4) information regarding the visual design and content, (5) support offered by the ECA, (6) information procedures to introduce the ECA to its user, and (7) formative evaluation. Each category could be completed by selecting the applicable predefined content, based on the study by Provoost et al [8] (see Supplementary materials 2.2 for all options). Conflicts between reviewers were identified and resolved by jointly reviewing the component and discussing the conflict, and these were documented in the logbook. When all the studies had been inventoried, we analyzed them thematically, which resulted in 3 topics. The first topic describes the different definitions and descriptions that were used for ECAs. The second topic describes the design and design processes of the ECAs, including their embodiment and communication modalities, applied theories, principles, and behavior change techniques (BCTs). To create a uniform language among the BCTs, the BCT Taxonomy (v1) from Michie et al [16] was used. The third topic describes the procedures, evaluation processes, and the efficacy and use-related outcomes.

Results

Study Selection and Characteristics

Figure 2 charts the screening and selection process. In total, 1789 unique studies were identified in the database search. Title and abstract screening resulted in the exclusion of

1754 studies. The remaining 35 studies were screened in full. Of those, 19 studies were excluded as the studies were not an intervention or did not include an ECA. This resulted in a total of 16 studies. One of these studies [4] described both a rehospitalization and a physical activity trial. As the first is not a lifestyle behavior, only the second trial was included in the analysis. A total of 4 more studies were found through snowballing [17–20]. This resulted in a total of 20 studies that were included in this review (see Supplementary materials 2.3 for a complete overview of the study characteristics).

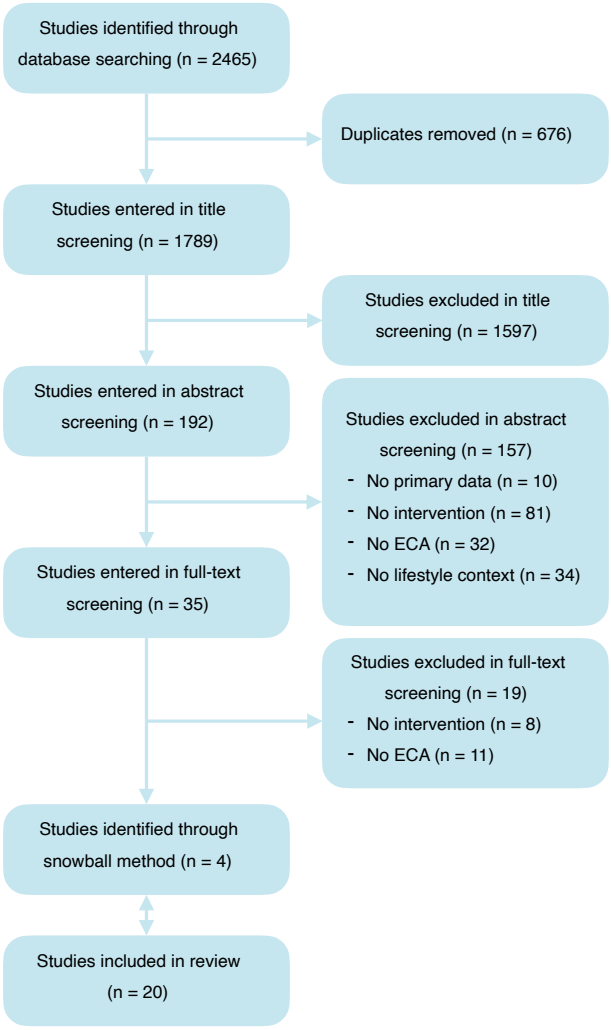

Figure 2: Flowchart describing study screening and selection.

The first studies were published in 2005 [3, 17, 21]. All the studies were either performed in the United States [3, 4, 17–19, 21–31] or in the Netherlands [5, 20, 32, 33]. Of all the studies performed in the United States, except for 1 study [26], TW Bickmore was listed

as an author. A total of 13 studies were in the pilot phase [3, 4, 17–19, 21, 24–26, 28, 30–32], 1 study was in the development phase [22], and 6 studies were in in the evaluation phase [20, 23, 27, 29, 31, 32]. Thus, none of the studies described the implementation or had actually implemented their ECA in practice. One ECA was used in a community setting and could be accessed via a computer kiosk [29]. All other ECAs were used at home and could be accessed via a website [20, 24, 26, 28, 30–32], or software installed on a PC [3, 17, 19, 21–23, 25], tablet [4, 18, 27], or mobile phone [33]. Only 1 ECA was part of an overarching platform, accessible via a website and an Android app [5]. Most studies targeted physical activity [3–5, 17–21, 23, 25, 27, 29–33]. Other lifestyle behaviors were nutrition [5, 20, 25, 30], mindfulness [26, 30], preconception care [24, 28], stress [30], blood glucose monitoring [5], and sun protection [31]. One study specifically targeted healthy lifestyles among diabetes patients. Patients may differ in their needs for lifestyle support compared with healthy individuals. This diversity in focus and target groups limits the comparability among the studies, and future research could help expand the evidence base for specific ECAs. Study designs varied from a randomized controlled trial (RCT) [3, 4, 17, 19–23, 25–30, 32, 33] to a pretest-posttest design, either with [31] or without control a control group [5, 18, 30]. Sample size ranged from 9 to 958 participants (median=60.5). Study duration lasted from 4 weeks to 36 months (median=8 weeks).

Descriptions and Definitions

Across the studies, 9 different names were used to describe an ECA, although the definitions were rather similar. A total of 6 studies used the name embodied conversational agent [3, 4, 19, 26, 27, 30], whereas the other studies used different names: relational agent [3, 17, 21, 22, 31], virtual coach [5, 23], virtual exercise coach [18], virtual avatar [32], virtual patient advocate [24], conversational agent [28], animated conversational agent [25], virtual advisor [29], personal digital coach [33], and persuasive computer assistant [20]. A total of 6 studies did not provide a definition for an ECA [5, 17, 20, 23, 25, 32]. All other studies referred to earlier with TW Bickmore listed as the author used variations of "an interactive, animated computer character that simulates face-to-face counseling" [5].

Design and Design Processes

Design: Embodiment, Communication Modality, Content, and Communication Strategy

All studies provided a screenshot of the agent. These images show that the embodiments of all ECAs were rather similar; 13 ECAs had the appearance of a middle-aged African American woman: 3 agents had an appearance similar to Laura [3, 17, 21], 6 agents were similar to Gabby [4, 18, 24, 27, 28, 30], and 5 agents were similar to Carmen [19, 22, 23, 25, 29]. Other ECAs were a white woman [26, 32, 33], a cat (the virtual iCat) [20], and an octopus [5]. In addition, 1 study used 4 different ECAs, using race and gender to match participants to one of the agents [31]. Thus, in total, there were 9 different agents.

These agents communicated through text [5, 19, 20, 32] or speech [3, 24, 31], or they allowed the user to choose between text or speech [33]. For the iCat, no information was provided [20]. Regarding the communication modalities, all but 1 agent [5] used facial and gaze expressions; in addition, only a few used hand and body gestures [3, 31]. Most users communicated with the agent by choosing a single response from a fixed list of responses [3, 19, 24, 26, 32]. Some agents also offered the possibility to type an answer in a textbox [26, 32]. A total of 2 studies did not provide any information on how users could communicate with the agent [20, 31].

Behavioral theories or therapy-derived principles were applied in a majority of the ECAs to drive their content and communication strategy. In total, 17 different theories and principles were mentioned in the 20 studies (median=3, range 1-4; see Supplementary materials 2.3 for an overview). A total of 3 studies did not mention any theory or principle [4, 22, 27], whereas the remaining studies did not discuss their interpretation or application. It is therefore unclear what role theories play in the design process. The Transtheoretical Model was mentioned most often [17, 19, 24, 25, 28, 29, 31, 33]; its application was, for example, described as "educational information based on current progress" [19]. Other theories or principles used more than once were as follows: Motivational Interviewing [20, 25, 28, 30, 32], for example, "cooperative feedback on the diary entries following the motivational interviewing concept" [20]; Social Cognitive Theory [19, 23, 25, 29] and Behavioral Theory [17, 23], for example, "the script employs behavioral and social cognitive strategies demonstrated in the literature to promote exercise behavior change" [23]; and Cognitive Behavioral Therapy [17, 18], for example, "the agent (...) uses a number of additional cognitive-behavioral techniques for health behavior change" [17]. In addition to or based on the theories and principles, the content and communication strategy also comprised BCTs. In total, 24 different BCTs were mentioned in the 20 studies (median=3, range 2-10; see Supplementary materials 2.3 for an overview). Again, 3 studies did not report any techniques [3, 21, 22]; the remaining studies did so very briefly. Furthermore, no uniform language was used to describe BCTs; therefore, it remained unclear how the BCTs were operationalized. Goal setting was mentioned most often [4, 5, 17–20, 23, 25, 27–32], and it was, for example, described as "weekly goals for exercise" [31]. Other frequently used BCTs were information about health consequences [5, 17–20, 23–26, 28, 30, 32], for example, "educational content about physical activity" [17]; problem solving [17, 18, 23, 25–28, 30–32], for example, "tailored strategies that addressed related barriers" [31]; social reward [5, 17, 19, 20, 23, 26, 27, 29, 31], for example, "positive reinforcement" [23]; feedback on behavior [4, 5, 18–20, 29, 31, 33], for example, "feedback about the behavior of the users" [33]; social support (practical) [5, 18, 27, 28, 30, 31, 33], for example, "exercise tip of the day" [18]; and self-monitoring of behavior [5, 17, 20, 29, 31, 33], for example, "self-monitoring charts" [27].

Design Processes

Regarding the design processes of the embodiment and communication modalities of the 9 different ECAs, 5 studies did not provide any information [19, 20, 26, 31, 33].

There was 1 study that provided some information, although very briefly: "The design of the gamification and coaching platform adheres to basic principles of healthcare, design principles for serious gaming as well as design principles for behavior change support systems" [5]. The remaining 3 studies did provide detailed information. A total of 2 studies reported on the design and the results of a focus group with end users, which resulted in the current appearance of the agent [24, 32]. The third study reported on the findings of various design methods: "Studies of interactions between human exercise trainers and their clients," a survey with end users and a literature review [3].

Regarding the design process of the content and communication strategies of the 20 ECAs, 9 studies did not provide any information [4, 5, 18, 19, 25–27, 29, 31]. In all, 2 studies [22, 28] referred to other publications [17, 24], which were also included in this review. Two studies each referred to a study, which is not part of this review, in which the design process is described: The first study [32] refers to a publication describing a pilot study on autonomous motivation and appreciation [34], and the second study [32] refers to a publication describing a survey with end users on the situation and timing of feedback [35]. A total of 3 studies provided some, very brief, information: "The ECA system for this study was adapted from the Gabby Preconception Health Care system's dialogue scripts and media" [30]; "Both the personal lifestyle goals and the feedback were evaluated and improved where necessary by a dietician" [20]; and "The 60 pages of educational content were assembled from publicly available web pages on exercise topics (...)" [3]. A total of 3 similar studies provided only some brief information, but these did include an interdisciplinary collaboration involving physicians, computer scientists, and exercise trainers to ensure adherence to best practices [17, 21, 23]. A final study used multiple methods and provided detailed information. It describes how they used scripts and media tools from previous studies and reports on a focus group in which they tested the content with end users [24].

Evaluation Processes and Outcomes

Evaluation Processes: Procedures and Measurement

A total of 7 studies did not provide any information regarding the procedures that were undertaken to introduce the ECA to its user [20, 21, 23, 26, 28, 31, 32]. The remaining studies only provided a short description. Most of the studies that did provide some information described a demonstration on how to use the system, which took place at the start of the study [3–5, 17–19, 22, 25, 27, 29, 30], for example, "participants were instructed on how to use the ECA system" [23]. For 1 study, participants were given "a brief group demonstration" [24]. However, another study sent "a user manual about the installation of the software" via email [33]. Another study sent instructions via email after 3 days of use [20]. Only 2 studies reported on assisting the user with user problems during the study: 1 study described contacting the user when the user stopped using the ECA [23]; the other study involved set times to check for technical issues [18].

Table 1: Differences in total number of efficacy and use-related outcomes between intervention and control group.

Outcome variable and measure	Significant[A]	Non significant[B]	No data[C]
Behavior			
Interview	-[D]	1	-
Other	-	1	1
Pedometer	2	3	2
Questionnaire	3	-	-
Self-report	-	1	1
Knowledge			
Interview	-	1	-
Questionnaire	-	1	1
Motivation			
Questionnaire	2	-	2
Usability			
Not reported	-	-	1
Questionnaire	1	-	4
Usage			
Log files	4	1	11
User satisfaction			
Interview	-	-	2
Questionnaire	-	2	14

[A] Significant positive difference between intervention group with and control group without an ECA.
[B] Non significant difference between intervention group with and control group without an ECA.
[C] Difference not applicable or not reported.
[D] An absence of outcome measure for the outcome variable.

Contrary to the procedures, the measurement of efficacy (behavioral, knowledge, and motivational parameters) and use (usability, usage, and user satisfaction parameters) was well described in all the studies (see Supplementary materials 2.2 for concept definitions, Supplementary materials 2.3 for an overview of all parameters, and Table 1 for a summary).

All the studies assessed a combination of multiple parameters (median=4.5, range 2-6). One study only described a protocol [19]; therefore, it was not considered in this section.

Regarding the efficacy parameters, behavior was assessed in all but 5 studies [4, 5, 24, 26, 31]. An example is the number of steps assessed by either a pedometer [3, 17, 21–23, 25, 27] or activity monitor [33]. Behavior was also assessed by self-report, usually in a questionnaire format [17, 19, 21, 23, 25, 28, 32], for example, "the usual weekly minutes of walking over the previous 4 weeks" [19]. Furthermore, a walking test for both distance and speed was used in 1 study [18]. Knowledge of the participant was assessed in 3 studies [20, 26, 30], and it was operationalized as lifestyle knowledge [20], food knowledge [30], or "conceptual and practical knowledge about mindfulness meditation" [26]. Knowledge

was assessed by either a questionnaire [20, 26] or an interview [30]. There were 4 studies describing users' motivation to change [19, 20, 24, 26], including stage of change [24, 26], motivation to fill in diary [20], and motivation processes of change [19], which were all assessed by a questionnaire.

Regarding the use-related parameters, 6 studies assessed whether users had had trouble using the intervention [3, 19, 20, 24, 25, 33] because of technical issues or lack of technical knowledge. Usability was assessed by a questionnaire [3, 20, 24, 25, 33]. One study did not report on how it assessed usability [19]. Usage was assessed in all but 3 studies [25, 31, 32]. All the studies assessed how and how often the intervention was used by log files. User satisfaction was assessed in all but 1 study [20]. Most often, single items were used to assess users' satisfaction with the interventions [3, 4, 17–19, 21–28, 30, 32, 33]. User satisfaction concerns items related to constructs such as liking, trust, and desire to continue using the ECA, for example, "How much do you trust Gabby?" [24]. Other methods used were interviews [3, 5, 17, 25, 30, 31, 33] and a focus group with end users [5].

Evaluation Outcomes: Efficacy and Use Related

When comparing the intervention group with an ECA with a control group without an ECA, more significant positive (n=12) than non significant effects were found (n=11; see Table 1). In other words, in 12 studies, the intervention groups showed improvement compared with the control group, whereas in 11 studies, there were no differences. However, for a majority of the outcome measures, this comparison was either not applicable as there was no control group without an ECA (n=37) or the significance level was not reported (n=4). Overall, 7 out of 15 studies reported better efficacy outcomes for the intervention group, and 5 out of 8 studies reported better use-related outcomes, compared with the control group.

Regarding the outcomes on behavior, it was found that participants using an ECA identified more preconception risks [28] compared with control participants only receiving an email. Both the studies on nutrition found no differences in eating patterns [30] and adherence to diet [20] between participants who had engaged with the ECA and participants who had not. In physical activity–related studies, 4 [19, 23, 27, 32] out of 8 studies [3, 17, 19, 21, 23, 27, 32, 33] found a positive difference in physical activity levels between participants who had engaged with the ECA and participants who had not. Regarding outcomes on knowledge, participants in the intervention arm did not score higher on lifestyle literacy, compared with control participants who had the same intervention without an ECA providing feedback [20]. Similarly, the food literacy outcomes of the participants in the intervention arm were not higher than those of the participants in the control arm, who had reviewed the same content with a research assistant once and received a CD with similar meditation recordings [30]. For motivational outcomes, the motivation to fill in a diary [20] and use of motivational behavior change strategies were higher for participants in the intervention arm [19] than for participants in the control arm.

Regarding the use-related outcomes, it was found that participants with an ECA considered the intervention as easier to use [20], compared with control participants who had the same intervention without an ECA providing feedback. Participants with an ECA also used the intervention more frequently [17, 20, 21, 26]. However, 1 study showed the opposite and reported a non significant effect for uptake on impact [23]. A total of 6 studies measured the usage over time, all showing a decrease [3, 4, 19, 22, 23, 27], for example, "A typical usage pattern was daily during the first week, tapering off to once or twice a week by the end of the study period" [3]. A total of 4 studies reported the average duration of a session, ranging from 12 min [24, 29] to 19 min [26, 28]. The average number of sessions during the intervention period was mentioned in 6 studies [18, 19, 23, 24, 27, 28], which was a median of 27.5 sessions (range 8 - 36). The intervention period of these studies was a median of 8.6 weeks (range 4 weeks - 4 months), and this was unrelated to the number of sessions. Participants interacting with an ECA did not report higher satisfaction outcomes [23], compared with control participants who could also view graphs and set goals without interacting with an ECA. In addition, participants in the intervention arm were equally satisfied with the ECA for improving health behaviors [30].

Discussion

Principal Findings

This scoping review charted the design and evaluation field of ECAs for coaching people in a healthy lifestyle. In total, 20 relevant studies were identified and analyzed. One could argue that the lack of diversity in research teams limits the external validity of the scoping review. However, although the work in this field is dominated by 1 research group, a careful comparison between research groups showed no differences in design and evaluation processes, as well as in outcomes (see Supplementary materials 2.3). We therefore conclude that the developmental processes described in this review are a realistic reflection of the field. Regarding the design, we found that studies often applied multiple theories or principles, but they did not report on their interpretation and application. Human-centered and stakeholder-inclusive design approaches tended to be unused. Regarding the evaluation, a combination of efficacy and use-related outcomes was assessed, usually in an RCT. However, rather than evaluating specific components, the intervention was evaluated as a whole. Overall, the studies included suggest that ECAs for coaching people in a healthy lifestyle can make an intervention more engaging, although evidence on their effectiveness remains inconclusive.

Myriad theories and therapy-derived principles were applied for creating ECAs' content and communication strategy. As it is difficult to determine what theory or principle best fits a specific context and as it is reasonable to assume that different contexts require the use of different theories and principles, we do not consider this diversity a problematic issue. However, what we do see as problematic is the lack of detail with which the incorporation of these theories and principles into functional or content design of an ECA is reported. If

how exactly an ECA works remains unclear, it will be difficult to learn from others' efforts or interpret the outcomes of evaluations performed with an ECA. This prevents knowledge accumulation about ECAs in general, as well as specific knowledge accumulation about which theories and principles are most appropriate in which contexts. A similar conclusion can be drawn with respect to the design process of ECAs. The design of an ECA can have a major effect on both impact and uptake. On the basis of empirical results of different studies on the appearance of ECAs, Baylor concludes that different appearances lead to different outcomes in terms of motivation and behavior change [36]. Unfortunately, reporting on the design activities and their results is generally incomplete or missing, thereby limiting the options for replication and learning from others' work. It is therefore recommended that future ECA work should not only present results on the efficacy of the ECA but also on the process leading to the design and content of the ECA.

With respect to the evaluation of ECAs for coaching people in a healthy lifestyle, we made a distinction between the results in ECAs' efficacy and use-related parameters. ECA outcome efficacy shows a non conclusive picture, operationalized as, for example, physical activity measured by an activity monitor, knowledge about mindfulness meditation as assessed via a survey, or diabetes-related emotional distress. About half of the evaluation outcomes show a significantly positive result for using an ECA, whereas the other half of the outcomes do not provide positive evidence. With regard to use-related outcomes, the evaluations do show a positive picture, where the majority of the studies indicate that the use of an ECA leads to higher ratings of usability or a higher degree of use. With regard to the efficacy-related outcomes, motivation to change had successfully improved in a majority of the studies, whereas health behavior and health literacy had not. On the basis of the existent evaluations, we can therefore state that ECAs do not necessarily lead to improved health outcomes; however, the intervention will at least be more engaging. This is in accordance with Provoost et al., based on their review of ECAs in clinical psychology and their evidence base [8].

Beyond the State of the Art

We found that end users are normally not involved with the visual design and content of the ECA. Rather, the ECAs were designed by professionals behind a desk. This practice contradicts human-centered or collaborative design approaches that are assumed to lead to technology appealing to and fitting the perspectives of the end users [37]. This consequently maximizes the chance of successful uptake of the technology [10]. In the literature, several practical approaches for human-centered design for eHealth are provided, such as the Centre for eHealth and Wellbeing Roadmap [11] or Integrate, Design, Assess, and Share [38], as well as a rich collection of case studies in which these approaches have been used [39, 40]. The field of developing and evaluating ECAs for eHealth would highly benefit from the reporting of similar case studies in diverse contexts.

We found that the evidence for using ECAs for coaching people in a healthy lifestyle remains inconclusive and that it is unclear which (combination of) components caused

a (lack of) behavior change. However, this problem is neither new nor exclusive to the field of ECAs; this so-called black box phenomenon has been acknowledged for eHealth interventions in general [32, 41]. Rather than evaluating an eHealth technology or ECAs for health purposes as a whole, an evaluation should focus on gaining insight into the effectiveness of the technology's or ECA's main or constituent components. A more fine-grained evaluation can be achieved by means of a factorial design, as this allows researchers to deliver specific intervention components to different groups of users [42]. Another strategy is to collect log files on usage time and patterns to identify the technology components that affect (non)use [37].

The studies in our review suggest that ECAs can make an eHealth intervention, aimed at improving people's lifestyle, more engaging. This is possibly because of the capacity of ECAs to establish and maintain an empathic relationship [3]. However, one can wonder how lasting this engagement is. Providing an ECA may have a novelty effect; thus, the engaging effect may wear off over time, resulting in decreased adherence, which is common for eHealth interventions [10]. Studying the use, effectiveness, and user experience of working with an ECA for coaching people in a healthy lifestyle for a prolonged period and in a realistic setting would provide inputs for answering these questions. Both researchers and eHealth developers need to find these answers to identify the persuasive goals that ECAs can serve best and to know how such ECAs should be developed to create engagement and a lasting effect.

Recommendations for Future Design and Research

On the basis of the findings of this review, we formulate several recommendations for future design and research. With respect to the development of ECAs for coaching people in a healthy lifestyle, we recommend the use of human-centered, stakeholder-inclusive design approaches, as well as reporting on the design activities in a systematic and comprehensive manner. This will allow others to learn from previous efforts. With respect to evaluation, there is a need to open the black box that is now pervasive among studies that delve into the efficacy of ECAs in improving health-related lifestyle. This means that evaluation reports need to specify which features are considered the main components of the eHealth intervention with an ECA and what theoretical foundation lies beneath these features, the ECA, and its persuasive tactic. Thereafter, during the data analysis phase of an evaluation, these features should be linked to measures of efficacy, use, and the user experience, to grasp whether the ECA works and why (not). Only in this way, a single evaluation can become valuable, both within and beyond its specific context.

Besides these general recommendations, we have also identified several specific research questions. As we mentioned in the introduction, the 24×7 availability of an ECA and its potential to deliver coaching at exactly the right moment (i.e., just before or after specific behavior) make it a potentially valuable addition to the persuasive tool kit that eHealth developers have at hand. However, none of the included studies focused on identifying the exact right timing for a specific type of content. Should we always try to prevent

negative behavior, thereby running the risk that the ECA may become annoying? Should we always acknowledge positive behavior, thereby running the risk that the ECA loses credibility? Finding the answers to these questions related to timing and frequency of use will allow us to create persuasive tactics for ECAs, which are in line with the tolerance levels and needs of end users. Furthermore, to fully understand the novelty effect that the introduction of an ECA may bring and to grasp the development of behavior change over time, longitudinal studies need to be performed. Ideally, these studies are (partly) in depth and qualitative to generate hypotheses for a novel field that can then be confirmed in large-scale quantitative studies afterward.

Limitations

The first limitation is that we might have missed relevant studies. The applied search strategy might have influenced our findings, as it is plausible that ongoing studies are only published in conference proceedings. The applied search string might also have influenced our findings. During the stage of identifying relevant keywords, we already found a variety of terms used to describe (comparable) ECAs. With the help of a librarian, we therefore tried to mitigate this risk by setting up a comprehensive list based on an initial search. In the end, we identified 9 different terms in the studies included, although the definitions were rather similar. As a recommendation for future work, we propose to use the term ECAs as the uniform term for "more or less autonomous and intelligent software entities with an embodiment used to communicate with the user" [2].

The second limitation relates to the identification of BCTs. They were rather difficult to identify as they were often mentioned summarily in the text or within images, and no uniform language was used, for example, we could only code Tailored strategies that addressed related barriers [31] as problem solving, according to the BCT Taxonomy (v1) from the study by Michie et al. [16]. Further descriptions were usually not provided.

Conclusions

ECAs are a promising tool for persuasive communication in the health domain. This scoping review provided valuable insight into the current development processes and evaluation outcomes. On the basis of these results, we offer multiple recommendations for future research agendas. We hope that the lessons from this review will further shape the novel field of using ECAs within the eHealth context.

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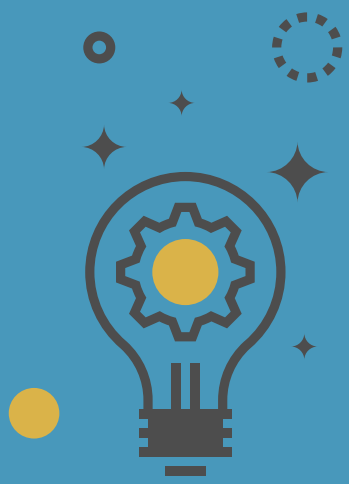

Chapter 3

Supporting eating behavior of community-dwelling older adults: Co-design of an embodied conversational agent

Abstract

In order to support community-dwelling older adults with healthy eating behaviors, Embodied Conversational Agents (ECAs) may be an effective and engaging medium. However, ECAs have not yet been found to be capable of engendering behavior change, which is partly attributed to the absence of a match with users' practices, needs and preferences. Hence, we describe a co-design process with older adults that informs both the content and the appearance of an ECA. Data was gathered through three consecutive iterations of co-design sessions with two groups of community-dwelling older adults in the Netherlands. Prior to the first session, participants completed a seven-day lifestyle diary. This study adds knowledge on the meaning of healthy eating, as well as on specific barriers to, and opportunities for, giving advice using an ECA in this target group. Furthermore, we translate this knowledge into general advice for designing an ECA in the context of health behavior change, while reflecting on a co-design process with older adults.

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Introduction

To help prevent or reduce the risk of chronic disease, support a healthy body weight, and enhance quality of life, community-dwelling older adults are recommended healthy eating patterns [1, 2]. In the Netherlands the National Health Council summarizes scientific evidence into the guidelines for such a diet. These guidelines are communicated by nutrition agencies to general populations and specific groups (e.g. through the Wheel of Five from the Netherlands Nutrition Center). A recent review suggest that factors influencing eating behaviors among this group interact across three domains: physiological changes associated with aging (e.g. taste, loss of appetite, and mobility limitations); psychosocial aspects (e.g. living alone, self-perceptions of health, and a desire to maintain independence), and personal resources (e.g. mobility and health literacy and skills) [3]. It is essential that interventions targeting eating behaviors of community-dwelling older adults consider these factors.

The use of digital technologies to improve health bears the potential to achieve this aim, and is gaining interest as a way to address health behavior change. As such, in recent years, several eHealth interventions improving eating behavior have seen the light of day [4–6]. One specific type of eHealth technology are Embodied Conversational Agents (ECAs). ECAs can be defined as 'more or less autonomous and intelligent software entities with an embodiment used to communicate with the user' [7]. Because establishing and maintaining an empathic relationship is the most crucial factor for successful lifestyle coaching [8], ECAs present a promising health coaching tool [9, 10]. In addition, compared to real-life coaches, ECAs are always available and can offer support when it matters most: immediately before or after specific behavior [11]. ECAs have great potential among our target group as well, as earlier studies show high ratings of acceptance, enjoyment and usability of ECAs among older adults [9, 12–15]. An example is 'Sylvia', which can be seen in Figure 1 [15]. Sylvia is part of a frailty assessment web app, and aims to counter frailty by offering older adults training modules in the domains of healthy nutrition and physical and cognitive training. However, although a recent review including 20 intervention studies shows that ECAs in the health context are more engaging then interventions without an ECA, they are not always successful in engendering an actual change in behavior, knowledge or motivation [16].

Despite the positive reactions from the target group towards ECAs, the technology is not yet successful in creating actual change. A recent review [16] suggests that target groups own views are usually not sought to inform the design process of ECAs in the field of health behavior change. This could result in a mismatch between the actual design and users' practices, needs and preferences, and therefore lower uptake and impact [17]. Human-centered design (HCD) aims to diminish this mismatch through an iterative approach in which researchers and designers cooperate with, and learn from, potential users in all steps of the design process [18]. Cooperation can be operationalized via co-design, a creative process in which users, researchers and designers actively collaborate and jointly explore the needs and goals of the end-users and the technology. The process includes,

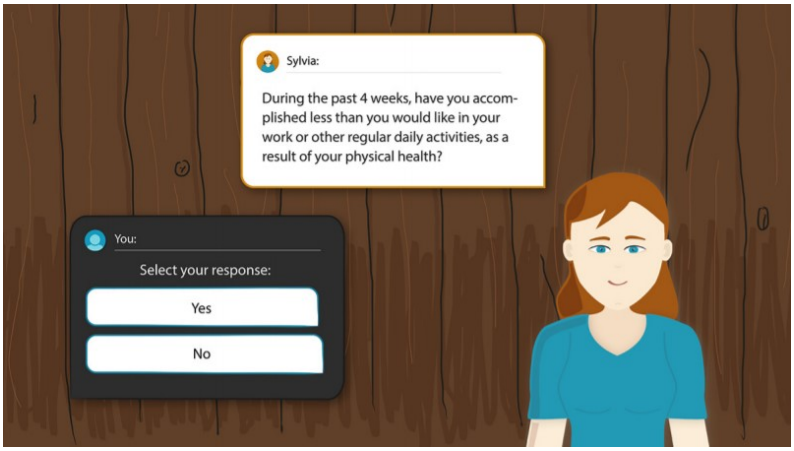

Figure 1: Example dialogue with 'Sylvia' [15].

for example, jointly exploring and envisioning ideas, creating and discussing sketches, and tinkering with mock-ups or prototypes [19]. Co-design is thus not simply asking users what they think of your design, but rather involving a group of users throughout the entire process, and actively working together. This process is linked to an improvement in both impact and uptake of eHealth technologies [17].

Given the increasing prevalence of diet-related, noncommunicable diseases among community-dwelling older adults, and the potential of ECAs, there is a strong case for applying an ECA for supporting healthy eating behavior. Therefore, the aim of the current paper is to describe a co-design process with older adults that informs both the content and the appearance of such an ECA. This study thus adds knowledge on the meaning of healthy eating, as well as on specific barriers to, and opportunities for, giving advice using an ECA in this target group. Furthermore, we translate this knowledge into general advice for designing an ECA in the context of health behavior change, while reflecting on a co-design process with older adults.

Methods

Participants

In this study we involved community-dwelling older adults in the Netherlands. We defined community-dwelling older adults as people who are retired and live at home. Participants were recruited in close collaboration with the National Foundation for the Elderly (NFE), a non-profit organization that aims to combat loneliness among older adults, via social activities and personal encounters. In this study we particularly involved participants of the 'community plus buses', as these are existing communities of people who conduct activities together. This made it easy for practical reasons as well as in organizing the discussions. We sent out an invitation to coordinators of these community plus buses.

Two coordinators responded positively, one of whom was located in the country side, and the other one was located in an urban region. We asked these coordinators to invite participants for our co-design sessions, which took place at a cheese factory, farm/country store and the headquarters of the NFE. The two groups participated separately in a first and second session, and were merged for a third session (see Table 1). Not all participants were able to join all sessions, because of illness and planning issues.

Table 1: Study setup, number of participants per session (session 1 and 2 were split) and aim.

	Participants		Aim
Diary	N=13		Trigger participants to think about their lifestyle
Session 1	N=4	N=8	Identify factors contributing to healthy living and (un)healthy eating
Session 2	N=4	N=7	Explore healthy eating advice
Session 3	N=9		Create the appearance of the ECA and its communication style

Procedure

Two weeks prior to the first session, participants received an information package. This package contained an information leaflet, an informed consent form, a seven-day diary, and a disposable camera. Participants were asked to fill out the diary prior to the first session, and to bring the consent form, diary and camera. Participants were brought to the site where we held the session, subsequently received a lunch, and were then invited to join a fun activity (visiting a cheese factory and farm/country store). During all sessions, discussions were held as open as possible, by allowing participant to share any views and information they brought forward. Moreover, the moderators actively looked for the broadest range of perspectives, including opposing views. Each session lasted for approximately four hours. At the end of the last session, participants received a cook book to thank them for participation, and were offered a newsletter informing them about follow-up studies. The protocol and all research materials were submitted to and approved by the Social Ethical Committee of Wageningen University & Research (CoC number: 09215846).

Diary

The aim of the diary was to obtain background information of the participants, and to trigger participants to think about their lifestyle. For demographics, participants were asked about their gender, age, educational level, household composition, marital status and number of children. To gain insight in participants' lifestyle, a combination of questions (e.g. 'Are you satisfied with your surroundings?') and assignments (e.g. a mind map) were used, based on the six aspects of the Positive Health framework; bodily functions, mental functions and perception, spiritual and existential health, quality of life, social and societal participation, and daily functioning [20]. Via a daily food diary sheet, participants were asked to write down what they consumed, with whom, by whom it was prepared, and whether they ate differently to usual. In addition, participants were asked to take a

picture daily (e.g. of their plate or fridge), in order to visualize the food context. The estimated time to fill out the diary was ten minutes a day.

Session 1

The aim of the first session was to identify and understand the factors contributing to healthy living and (un)healthy eating, and the context in which these take place. Apart from the introduction and conclusion, the session consisted of two parts:

- Questions: "What does a healthy lifestyle mean to you?" and "What does healthy food mean to you?" Answers were first written down individually by participants, followed by a plenary discussion during which all answers were written down on a flip-chart by the moderator, thus creating a list of answers. Then, the favorite answers were chosen by the group.
- Assignment: Participants received answering sheets and sticky notes, and were asked to use their diary to categorize consumed foods and their degree of healthiness. They then were asked to add a description of the moment during which unhealthy items were consumed. Next, small groups were formed and participants provided advice to each other on the moments of unhealthy eating. The assignment was followed by a plenary discussion.

Session 2

The aim of the second session was to explore healthy eating advice considered suitable by older adults. The session consisted of the following questions and assignment:

- Questions: 'What would be the preferred way to approach you about healthy eating?' and 'What kind of tone of voice should these messages have and how does such a message reach you?' Answering sheets were provided (see Figure 2), and the assignment was followed by a plenary discussion.
- Assignment: Three personas and scripts (both based on the first session) were presented to subgroups. The central question was: 'What kind of advice could be given to the fictitious person in the story and what kind of signals/sounds/tone of voice (e.g. sound, vibration, voice; also see Figure 2) could become part of the storyline?' Participants received answering sheet containing a 7-day timeline (see Figure 2), which they were asked to fill in, in order to create an overview of the number, time, and type of healthy eating advice. All timelines were discussed afterwards in plenary.

Session 3

The aim of the third session was to create the appearance of the ECA and its communication style. Both groups were merged and, after an introduction, the session started by introducing and discussing the concept of the ECA, whereby no visuals were used. This session consisted of two assignments:

Figure 2: Answer sheets sessions 2.

Note. English translation: 'From whom would you like to receive tips & advice regarding healthy eating/living?' 'Which signal / sound / 'tone of voice' do you prefer?' 'Sunday, Monday, Tuesday. Timeline'.

- Assignment 1: Visualize what an ECA should look like according to you. Magazines, scissors, pencils, tape and other tools were provided. After an hour, each participant was asked to explain his/her design choices and elaborate on the personality and role of their ECA.
- Assignment 2: Three written dialogues with the same content, but different in length and tone of voice were provided (based on previous sessions). Participants were asked to choose one of the three dialogues as their favorite dialogue and to provide a rationale for their choice, which was discussed afterwards.

Data analyses

Scans were made of the diaries, pictures, answering sheets, and work-sheets. Audio recordings of the sessions were transcribed verbatim by an independent agency and reviewed by the research team for accuracy by comparing the audio recordings with the written transcripts. Pseudonyms were developed for each participant to maintain confidentiality. All data was uploaded in ATLAS.ti qualitative data analysis software. Analysis was guided by a thematic analysis approach, and combined a deductive and inductive approach [21]. Literature was used to define deductive codes, and consisted of the framework for Positive Health [20], a list of food groups used to define aspects of healthy eating [22], a list of perceived benefits of healthy eating [23], a list of perceived barrier statements towards healthy eating [24], and a list of behavioral change techniques [25]. One researcher (LK) read and reread all transcripts in order to identify an initial list of inductive codes. The codebook was further developed independently by two researchers (LK, MB), merged, and differences were discussed, leading to a final and agreed upon codebook (see Supplementary materials 3). This codebook was used to create thematic maps to cluster and categorize the data. The following four themes emerged: Better diet, source and medium of healthy eating advice, ECA and other. The following thematic maps were created: Healthy living, healthy eating, perceived barriers, healthy eating advice, and personality traits. See Figure 3 for two of these thematic maps.

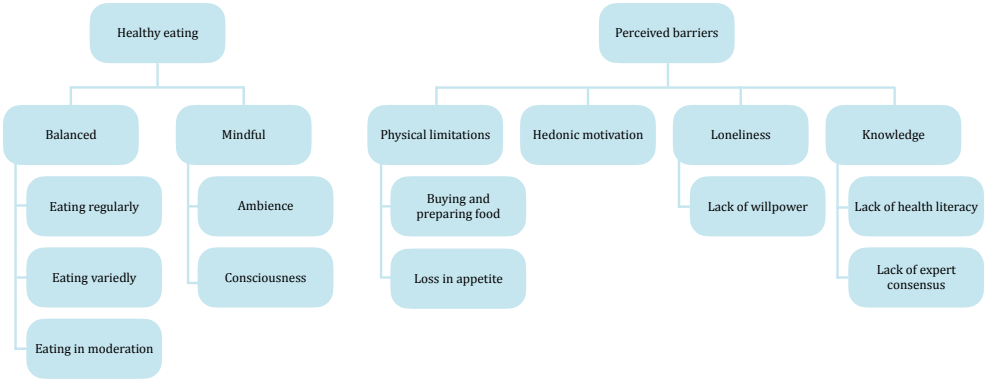

Figure 3: Thematic maps healthy eating and perceived barriers for healthy eating.

Results

Demographics

The total sample consisted of one male and twelve female participants, ranging from 69-92 years of age (M=88, SD=7.04). A majority completed at least high school (8/13), other participants' highest completed level of education was college education (2/13), vocational education (2/13) and elementary school (1/13). Most participants were single; almost all had been married (12/13), but their partners in most cases passed away (11/12). Thus, only one participant was living together with their spouse. More than three-quarters of the sample had children (10/13), ranging from 1-4 children (M=2), all of which had left the parental home.

The Diary

Understanding the context

Typical eating behavior of participants included having a cracker or yogurt for breakfast, two sandwiches for lunch, and potatoes with vegetables and meat for diner (see Figure 4). S/he consumed what s/he had planned, and often consumed the same foods every day (especially for breakfast and lunch). The meals were usually prepared him- or herself, and eaten without company. Daily activities often consisted of household chores, spending time on the computer, reading a book or the newspaper, and, if possible, some form of physical activity (e.g. walking or cycling). In order to increase self-perceived health, a good dietary pattern and ample physical activity were deemed important. Physical limitations were experienced as an important obstruction to perform various physical activities, such as spending time outdoors. Overall, the quality of life was rated as quite satisfying, although loneliness, and a lack of social contacts, was often mentioned as a major factor for a poorer quality.

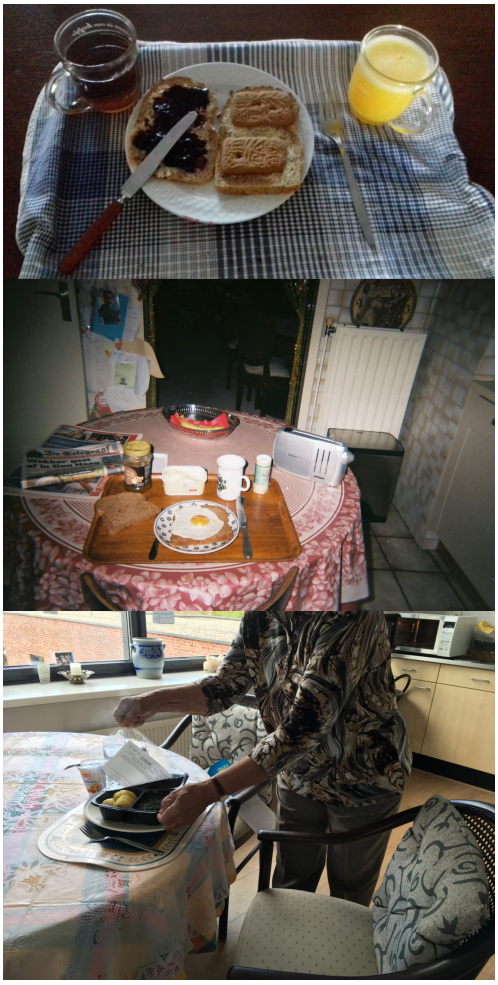

Figure 4: Pictures of a meal (participants, from top to bottom: F, 92; F, 84; F,83).

"I would like to have more contacts, but everybody is busy." (F, 88)
"The sad moment at the end of the day when eating alone and coming home alone." (F, 69)

After filling out the diary for seven days, participants often indicated how much they appreciated the attention which was given to older adults in general via this study. They also mentioned regularly that the diary made them more aware of their current eating behaviors.

"With great pleasure I have completed this diary, and look forward to discussing all these topics with others. Thank you for organizing this course for the older adults." (F, 85)

The co-design sessions

Creating content: Healthy living

The most important aspects of healthy living mentioned could be divided into four themes: 'social context', 'autonomy', 'positive mindset' and 'nature' (see Figure 3). The social context, related to not feeling lonely and having many social contacts, was mentioned most often. For example, one participant moved to another neighborhood where she could be with people her age. For her, this was an important step to increase her quality of life. The second theme, autonomy, referred to the desire to maintain independence in old age. One participant explained this by telling a story of how her grandchildren kept mentioning that 'mommy wants to do it herself'. This also included dealing with physical limitations, which were discussed frequently, as these were seen as limiting a healthy life. For example, because of mobility limitations participants were not able to visit family members, or because arthritis made it difficult to go cycling. Two other themes were having a positive mindset and spending time in the nature. They agreed it was important to think positively, which made them feel happier. Furthermore, they felt they were living healthier when frequently spending time in nature, which made them feel good. Three out of four themes, and how they are interrelated, were perfectly summarized by one of the participants during the session:

"I wrote down mens sana in corpore sano. And that means a healthy mind in a healthy body. Well having said this, this obviously means a lot. For me, that means that you feel comfortable by lots of open air, not too much food and drinks, good contacts with neighbors around you and no illness please." (F, 75)

Creating content: Healthy eating

The most important aspects of healthy eating could be divided into the themes 'balanced' and 'mindful' (see Figure 3). In addition, fresh and natural foods were also mentioned a couple of times as being healthy.

Balanced was by far the most important theme, and was mentioned often and throughout all sessions, both related to a healthy lifestyle in general and to healthy eating more specifically. When discussed further, three subthemes emerged for balanced. The first subtheme was 'eating regularly', and meant eating throughout the day and at set times. Participants explained that it was something they had learned when they were young. The second subtheme was 'eating variedly', and referred to the consumption of different foods every day. For example, different spreads on bread and different kinds of fruits. The last subtheme was 'eating in moderation', referring to eating a suitable portion size. Participants commented that they did not feel well when they ate too much.

Mindful referred to the activity of eating, beyond the actual consumption of foods. Two subthemes emerged; 'ambience' and 'consciousness'. Ambience referred to making the meal 'cozy', for example by sitting at the table with candle light. Although some felt it was too confronting to make it cozy, since it put the emphasis on being lonely. Consciousness

referred to the enjoying of food, via little bites and with all attention towards the process of eating.

Creating content: Perceived barriers and healthy eating advice

When discussing the perceived barriers of the participants towards healthy eating, four themes could be distinguished: 'Physical limitations', 'hedonic motivation' 'loneliness' and 'knowledge' (see Figure 2).

A first and most often mentioned physical barrier towards a healthier diet was the process of buying and preparing food. When the body ages, it was often mentioned that these tasks become harder and cost too much effort. The participants also discussed the use of meal-delivery companies, but were rather negative about the quality and service. A second physical limitation was the loss of appetite, both for foods and drinks. Participants found it difficult sometimes to remember to eat if their body did not indicate any appetite. During the session, we asked participants to share pieces of advice with others, in order to help them overcome their perceived barriers. Although not all participants were interested in changing their eating behavior, they all actively contributed to the discussion and had clear ideas and opinions. When discussing the pieces of advice, it became clear that a variety of practical tips was already applied. These include buying pre-cooked vegetables, asking for smaller senior portions in restaurants, or spreading cooking activities over the day. Participants also mentioned how they liked learning from each other, and already applied various advice from other participants in between sessions.

"I prefer self-cooked. And I find that difficult these days. Because I have a limitation and then with the gas and the draining of hot water for your potatoes. That is hard though." (F, 88)

Second, participants explained that they were motivated rather hedonically; they felt that they were old enough and should be allowed to 'cheat' and 'enjoy foods', for example, during birthday parties. This was confirmed by the diaries, in which they reported that most 'unhealthy foods' were consumed during social activities. Some also felt that people should not be 'forbidden' to eat unhealthy foods. Participants were most interested in receiving small and practical tips in order to 'cheat less'. The tip mentioned most often by the group was finding a healthier substitute. This related, for example, to the 'half past five moment', when one craves something salty. Instead of having some chips, they advised choosing a broth soup. Next were the mindfulness tips. Similar to one of the definitions of healthy eating, participants advised to eat 'consciously'. For them, this included listening to their own body. For example, responding to signals when one has eaten enough. Last were the practical tips, including doing groceries with a full stomach, drinking plenty of water, and choosing a smaller portion size.

The topic loneliness recurred frequently during all sessions. During the discussion of healthy living, social contacts were often mentioned as an important driver for a healthy lifestyle. In relation to eating, an absence of others to share a meal with seemed to instill a lack of willpower to prepare a meal. A first barrier was that participants did not find it worthwhile

to cook a meal for one person only. Second, they did not feel comfortable to consume a meal without company. When discussing the various type of advice, the piece of advice that was mentioned most often was to go out and contact other people. Participants often mentioned that they cannot simply wait inside for people to contact them. However, it was also indicated by multiple participants that this is not always easy, as feeling lonely is often related to a lack of energy for finding and maintaining social contact.

The theme knowledge related to a lack of expert consensus, something which seemed to confuse them (e.g. with regard to drinking wine). They found it rather confusing that scientific insights change over time, and it made them follow their own common sense. This also related to a lack of health literacy. Some particular foods were discussed, and it became clear that health literacy differs among the participants (e.g. healthiness of orange juice, nuts, and certain biscuits). Pieces of advice to overcome the knowledge barrier consisted of looking online and in magazines for information.

From content to visualization: Source and medium of healthy eating advice

We asked participants about who should give them advice and how this message should reach them. Different suitable sources for bits of healthy eating advice were found: 'me', children, and the culinary specialist. The first person was the participant him or herself. Their reasoning was in line with their aforementioned need for autonomy. They knew what is best for themselves and preferred to actively find information themselves, for example through magazines or via the Internet. The second preferred source were their children. Participants agreed that they generally accepted suggestions with regard to healthy eating habits from their children. They could imagine a video message by their children, which could be broadcasted via their television, could be useful. A last source is the culinary specialist, for example a cook. They generally agreed that the cook was a credible source when it comes to preparing meals. Participants suggested for these messages to be sent via various cooking shows and cooking magazines.

When discussing the role of the dietician and GP, the opinions varied. Participants agreed they were both a credible source. However, some participants associated a dietician and GP purely with 'medical advice' and found them too patronizing, which made them not a suitable source for healthy eating suggestions.

"[I prefer my daughter] better than an annoying dietician, whom I have a fight with within 30 seconds. You go to the general practitioner and then they will put you in contact with a dietician. Please do, I am outside within two seconds. Because they know, they only talk about apples and nuts..." (M, 69)

Visualization: Appearance and communication style

When we first introduced the concept of an ECA in the third session, participants reacted with resistance and misperception towards the technology. Participants thought, for example, that someone behind the scenes needed to control the ECA in real-time. However,

this changed when one of the participants shared her positive experience with seeing an assistive robot on television. Thus, when the benefit of an ECA became clear, participants seemed to rethink their opinion.

The assignment remained challenging for some participants. Most found it easier to discuss their own health behavior over the design of a fictional ECA. But in the end, all participants did design an ECA, although very different from each other (see Figure 5). We did not provide an example, and participants were free in choosing their own method. Some participants drew a human-like figure, while other participants wrote about a strip figure (Tom Poes), or created a mood board from magazines. During the plenary discussion about their thoughts, ideas and design motivations we held afterwards, it became clear that the style should be either a cartoon or realistic, but not something in between. Participants mentioned that they found the in-between styles rather scary. Regarding gender and race there were no clear opinions. Ultimately, there were five commonly preferred personality traits: 'friendly', 'warm', 'trustworthy', 'concerned' and 'competent' (see Table 2). The tone of voice should fit these characteristics, but very importantly, it should absolutely not be patronizing, and should include some humor. This was mentioned multiple times throughout the sessions, by different participants. They further mentioned that the preferred tone of voice depends on the context

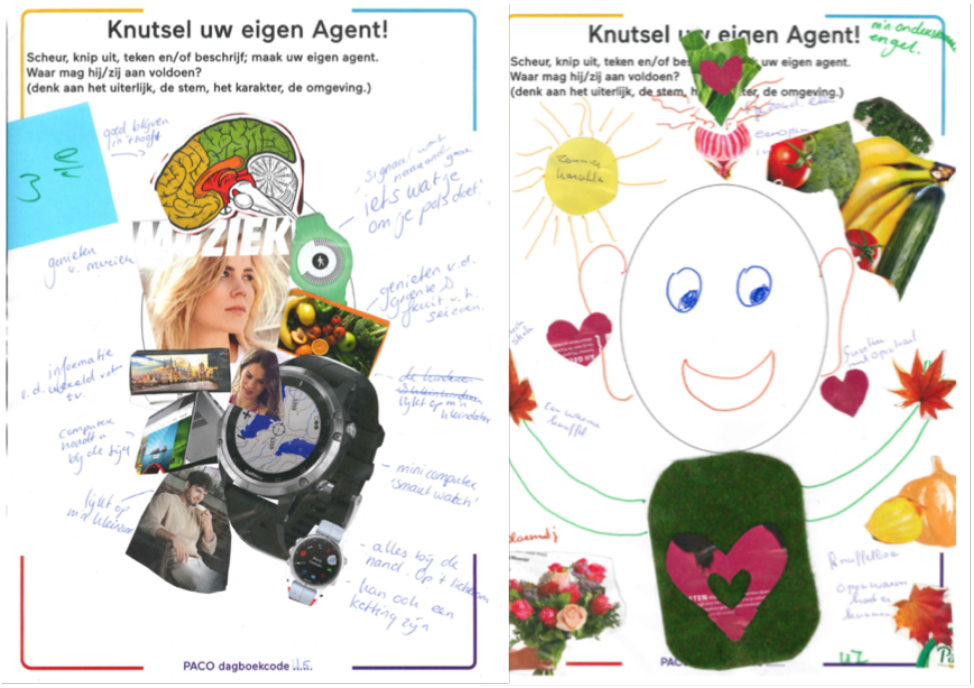

Figure 5: Two ECAs as designed by participants.

Table 2: Preferred personality traits.

Personality trait	Example quote
Friendly	"Friendly, not controlling. Then I am immediately antagonized..."(F,88). "Yes, I am old, not retarded." (F, 75)
Warm	"And also, with warm thinking, with a heart full of warm thinking. Yes, that's that heart, isn't it?" (F, 88)
Trustworthy	"Helpful in the background, but [the agent] knows how to intervene at the right time." (F, 83)
Concerned	"Offering a helping hand." (F, 73). "...and occasionally bring a flower for the weekend" (F, 85)
Competent	".. it has to be sweet, intelligent, and able to participate in discussions." (F, 84)

Discussion

Principal findings

Via the diary and co-design sessions, we explored how an ECA could support community-dwelling older adults with healthy eating. The first main finding is that older adults approach eating from a holistic perspective. This means that they do not only evaluate eating in terms of nutrients, ingredients, or components, but in terms of eating mindful and well-balanced. This holistic perspective also means that it is important for developers to understand the target group's views on healthy living, in order to understand healthy eating. Second, action planning and self-monitoring are the preferred approaches towards changing eating behavior among older adults. The aim is to increase perceived competence levels, support autonomy and address feelings of loneliness. The third and last main finding is that ECAs bear the potential to support older adults with healthy eating behaviors in an engaging manner. However, it remains important to consider possible underlying health issues many older adults face. Considering the context, these principal findings should guide the development of the content of the ECA. Finally, we propose three recommendations for designing the appearance of the ECA.

Comparison with prior studies

We found that healthy living for older adults means that they are satisfied with one's social context, feel autonomous, have a positive mindset and spend ample time in nature. This perspective on healthy living neatly aligns with the Self-Determination Theory (SDT) of Ryan and Deci [26]. Briefly, SDT postulates that human beings have three essential psychological needs – autonomy (feeling of being the origin of one's own behaviors), competence (feeling effective), and relatedness (feeling understood and cared for by others). Both the social context and autonomy as identified in the present study are clearly in line with the SDT. Feeling competent was not directly discussed, but was reflected in the various practical skills discussed for healthy eating participants mastered in order to cope with their (physical) limitations due to the process of aging.

Having physical limitations, feeling lonely, and lack of knowledge, were experienced as barriers towards healthy eating. These barriers all fall within the key domains of factors influencing eating behaviors, as identified in a systematic literature review by Host et al. [3]. Our study adds hedonic motivation, i.e. enjoying foods, to this list. As hedonic hunger is not predictive of weight regulation [27], it illustrates why interventions should not prohibit the consumption of 'unhealthier' foods. Instead, interventions should address the individual needs, and stimulate, for example, healthier substitutes or eating mindfully. This is a change strategy which is often applied in SDT-based interventions [28]. In the present study, action planning and self-monitoring were mentioned as the most suitable behavior change techniques (BCTs), whereby practical suggestions from peers could inspire other older adults. Research shows that these BCTs, which facilitate self-regulation of behavior, are indeed associated with effectively changing healthy eating behaviors in the long term [28].

Design advice

The design of an ECA should, ideally, always be based on the needs and preferences of the specific target group. Based on our study, we formulated the following three design advice:

- Include the following personality characteristics into the ECA: friendly, warm, trustworthy, concerned, and competent.
- Match the role of the ECA to the topic.
- Use informational, non-judgmental language and include humor.

Interestingly, the personality characteristics we identified via an open discussion resemble the most important personality characteristics identified by ter Stal et al.[29], following a card-sorting task. The exception is the characteristic 'warm', which was deemed important in our study, and not in their study. According to older adults, the personality characteristics of an ECA are more important than their appearances [29]. While co-designing an ECA, we therefore recommend designers to ask users to rate the ECA on these five characteristics, and, if needed, discuss how the design can be improved to match these characteristics more closely.

When discussing the source of healthy eating advice, it became clear that people have different preferences regarding the source of the advice, which also depended on the topic at hand. For example, they found a cook suitable for receiving recipes, but preferred discussing more sensitive issues with their children. This implies that different health topics might require ECAs in different roles, providing different type of advice [30]. However, none of the current ECA-based interventions consider different roles [16]. We therefore advise to test whether the ECAs' role (e.g. a cook or peer) matches the topic at hand (e.g. viewing recipes or providing mindfulness tips).

The importance of using informational, non-judgmental language, is reflected by the need for autonomy [26, 31]. According to Teixeira et al. [31], one way to achieve this is by

using language that conveys freedom of choice, collaboration, and possibility. They advise to avoid constraining, pressuring, or guilt-inducing language (e.g. use 'might' or 'could' instead of 'should' and 'must'). In addition, we emphasize the importance of using humor in the communication style. This is not a new practice, as one of the first ECAs in the field of health behavior change already includes humor [32].

Reflection on a co-design process with older adults

We would like to emphasize how the process of co-design turned out to be a positive experience for both participants and researchers. We aimed to create an engaging setting, starting with the diary, which had an appealing layout and a positive tone of voice. We also clearly emphasized that the older adults were the experts. So, we also treated them in this way, and mentioned that their important contribution was used to generate new scientific insights. In addition, we arranged transport, lunch and an appealing location. This setup required a rather high time (and financial) investment, but did return in an intrinsic motivation of participants to discuss their lifestyle and nutritional pattern, and to share emotional stories. At the end of the last sessions, participants were even eager to being kept informed about the project and participate in any further studies. They also let us know that they highly appreciated the attention which was given to them as a group.

Conclusion

We explored how an ECA could support older adults to improve their eating behavior. Therefore, a thorough understanding of the drivers for their behavior is needed. It is important to realize that older adults do not evaluate food in terms of nutrients, but in terms of eating mindfully and in a well-balanced manner. Furthermore, the broader concept of healthy living needs to be understood in order to understand healthy eating. The preferred behavior change techniques towards healthy eating behavior are action planning and self-monitoring. These techniques should aim to increase perceived competence levels, support autonomy and address feelings of loneliness. An ECA has the potential to support older adults in this, whereby a combination of humor and the use of non-judgmental language is an important asset. Designers are advised to select the right role for the ECA, combine the most important personality characteristics, and use informational, non-judgmental language, as it increases the chance of engendering behavior change.

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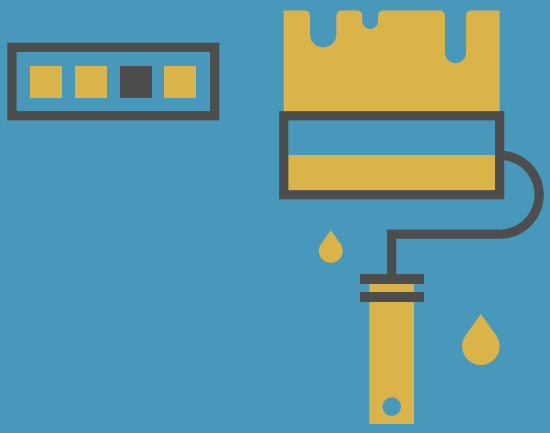

Chapter 4

Optimizing appreciation and persuasion of embodied conversational agents for health behavior change: A design experiment and focus group study

Abstract

Embodied Conversational Agents (ECAs) can increase user engagement and involvement and can strengthen the effect of an intervention on health outcomes that is provided via an ECA. However, evidence regarding the effectiveness of ECAs on health outcomes is still limited. In this article, we report on a study that has the goal to identify the effect of a match between a health topic and the ECAs' appearance on ratings of personality characteristics, persuasiveness and intention to use. We report on an online experiment with three different ECAs and three different health topics, conducted among 732 older adults. We triangulated the quantitative results with qualitative insights from a focus group. The results reveal that older adults prefer an ECA that has an appearance matching a certain health topic, resulting in higher ratings on persuasiveness and intention to use. Personality characteristics should be measured embedded within a health topic, but are not rated higher because of a match. We furthermore provide guidelines for designing the content of the ECA.

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Introduction

eHealth is in a transition phase, whereby text- or video-based communication is gradually being replaced by more engaging means of interaction. Examples of such means are online videos and games, and also Embodied Conversational Agents (ECAs). ECAs have been defined as "more or less autonomous and intelligent software entities with an embodiment used to communicate with the user" [1]. Most often, they take the form of virtual persons or cartoon characters on websites, accompanied by a scripted chat functionality. Compared to traditional text, video or audio communication, ECAs provide a form of simulated human to human interaction, whereby natural dialogues are aimed to be mimicked (including interactive scripts and body language).

Previously, ECAs have been implemented within the health context for a variety of contexts, such as health education [2], mental disorders [3], or as a decision aid for shared decision making in healthcare [4]. Using an ECA to convey information, to offer an intervention, or to support decision making has been found to sort different effects. A review by Provoost and colleagues [5] found that ECAs can increase user engagement and involvement, and can strengthen the effect of an offline intervention that is provided alongside the ECA. At the same time, they conclude that the evidence regarding the effectiveness of ECAs is still limited, as it is an emerging field and most studies have focused on usability and user acceptance. A similar conclusion was drawn in a review by Kramer et al. [6], who found that, on the one hand, using ECAs leads to higher usability and use of a digital intervention, but that the effect of using ECAs on health outcomes is still unclear. Often, motivation to change increased, but health behavior and health literacy did not. A prerequisite for use and effect of an ECA within any context, including health, is a proper and engaging design. Multiple studies have concluded that the design of an ECA should instill emotional bonding with the end-user [7–9]. Most of the studies, aimed at generating design guidelines for ECAs in the health context, have focused on the design of speech or textual output, ECA gaze and facial expressions, and body gestures, while the design of the ECA's appearance seems to be somewhat neglected [6, 10].

The influence of appearance

As supported by research with humans, an ECA's appearance is essential in influencing users motivation, attitude and future behaviors. For example, people prefer for a health-care provider to wear a white coat or a professional dress [11], for a physiotherapist to wear a tailored dress [12], and for female therapists to wear casual attire [13]. These preferences are found to communicate expertise and authority [12, 14]. Hence, they have an important influence on patient trust levels, establish confidence, influence the perception of empathy, and increase the likelihood that patients will comply with care instructions [14, 15]. This effect goes beyond attire; it is long known that relative to a physically unattractive counselor, an attractive counselor is perceived more favorably with regard to her competence, professionalism, assertiveness, interest, and relaxation, and her ability to help with problems [16].

Similar to the finding that humans are influenced by the appearance of humans, they are also influenced by the appearance of ECAs. Different studies on appearance of ECAs conclude that different appearances lead to different outcomes in terms of motivation and behavior change [17], regardless of the underlying technical system. Baylor and colleagues showed, for example, that an attractive and 'cool' agent leads to higher levels of motivations among youngsters, because it most closely reflected themselves [18]. Furthermore, a recent study by ter Stal and colleagues [19] found that an ECA's appearance effects the users' perception of authority, whereby older male agents were seen as more authoritative than young female agents. In another study, ter Stal and colleagues showed that the agent's role (e.g. a peer or expert) also effects the perception of the agent's characteristics, such as trust and friendliness, but also the likeliness of following the agent's advice [20]. Thus, adapting the appearance not only influences first impressions, but also future interactions between the user and ECA.

Persuasiveness and personality

In general, the goal for an eHealth intervention is to persuade end-users into using the intervention and complying with the desired behavior (e.g., losing weight or monitoring their health status). By taking into account persuasive strategies or functionalities in the design of an eHealth intervention, one can increase end-user adherence [21]. An overview of these design principles has been created by Oinas-Kukkonen and Harjumaa [22] and includes features such as rewards, third-party endorsement, and instilling authority. However, implementing these features (either with or without an ECA) should not be seen as the magic bullet for creating a successful eHealth intervention. Rather, the design should be tailored towards the target group and the health-related behavior goal [23, 24].

Tailoring the design of an ECA can be done by adapting the dialogue script, its body language, or its appearance, all part of an ECA's personality. Leading to the question which personality traits are ideally incorporated in an ECA. Existing studies on ECAs measure user satisfaction via characteristics as liking, trust and friendliness [25, 26]. In a previous study, we set up multiple co-design sessions with community-dwelling older adults in which we discussed which personality traits they would prefer for a health ECA. We found that the most valued traits among this group were friendliness, warmth, trustworthiness, concern and competence [27]. These traits, with the exception of 'warmth', were also identified as most important among older adults in a card-sorting task study by ter Stal et al. [20]. These findings indicate that associating the right personality traits with appearance to an ECA for a specific health-related behavioral goal, might increase the persuasiveness, and hence appreciation and effect.

Research objectives

In this article, we report on an experiment with three different ECAs and three different health topics. The aim is to identify the effect of a match between a health topic and the

ECAs' appearance on ratings of personality characteristics, persuasiveness and intention to use. The ultimate goal is hereby to create design guidelines for ECA design that ensures high persuasiveness and intention to use. To this goal, we conducted an online experiment among older adults and triangulated the quantitative results with qualitative insights from a focus group. The main research question that we formulated goes: *How does the match between a health topic addressed by an ECA and the ECAs' appearance effect end-users' evaluation of the ECAs personality characteristics and persuasiveness?*

To guide this study, we formulated three hypotheses, based on the literature discussed above:

1. When an ECA is embedded in a health topic, it is rated higher on positive personality traits (friendliness, warmth, trustworthiness, concern, and competence).
2. Older adults prefer an ECA that has an appearance matching a health topic (cooking, food, and loneliness).
3. An ECA that has an appearance matching a health topic is rated higher on positive personality traits, persuasiveness and intention to use.

Method

Method online experiment

Participants

Participants were recruited via a Dutch research panel of the National Foundation for the Elderly, consisting of approximately 1350, mainly community-dwelling, older adults. Participants received an email asking whether they were willing to participate in the online questionnaire. The only inclusion criterion was that participants should be fluent in the Dutch language. In addition, community-dwelling older adults whom participated in a previous study of the same project were invited per newsletter to complete the questionnaire [27]. Since four participants previously indicated a preference to receive documents per post, they received a paper version of the questionnaire.

Stimuli

Based on a previous co-creation study with community-dwelling older adults in the Netherlands [27], we created three different ECAs, with different names and personas (see Figure 1). The first ECA represents a female peer (Ellen), the second ECA a cook (Herman) and the third ECA a fantasy figure (Bo).

In addition, and also based on the co-creation study, we created three storyboards (see Supplementary materials 4). Each storyboard addressed a different health topic, and was based on a different behavior change technique (BCT). The first context was 'Cooking', and included a recipe book with the BCT tailoring, with the aim to improve eating behavior. The second context was 'Food', consisting of a food diary via which users self-monitor

their eating behavior. The third and last context was 'Loneliness', and consisted of a bundle of audio-fragments from other older adults about social activities they performed, based on the BCT social learning, with the aim to decrease loneliness.

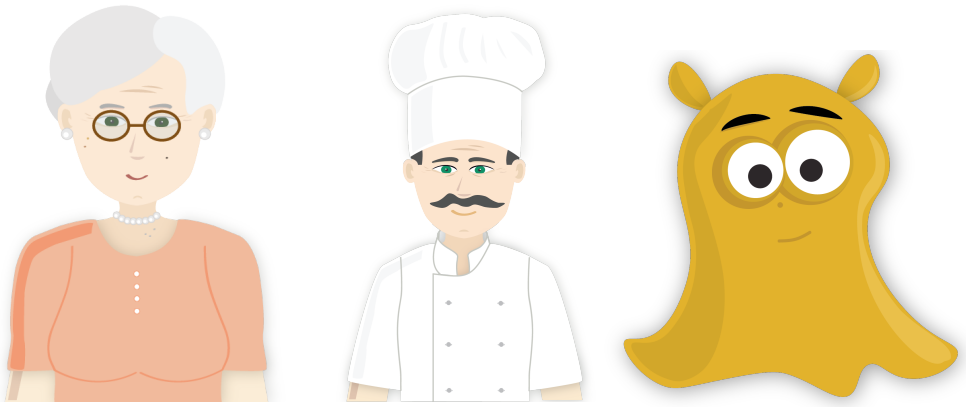

Figure 1: The three different ECAs (Ellen, Herman and Bo).

Procedure

The online survey tool Qualtrics was used for the questionnaire. After providing informed consent and completing the questions on the socio-demographics, participants were randomized. A quarter of the participants were randomly assigned to questionnaire A, three quarters of all participants were randomly assigned to questionnaire B (see Figure 2).

In questionnaire A, participants were asked to rate the appearance of the three different ECAs on five personality characteristics. They only viewed the image of the ECA (similar to Figure 1). Next, participants were asked to indicate the importance of the five characteristics. Last, participants viewed three different storyboards without an ECA (see Supplementary materials 4), and were asked which of the three ECAs would be able to help them best.

In questionnaire B, participants were further randomized over 1 of 3 groups. Each group of participants viewed three storyboards, each with a different ECA addressing a different health topic (thus, there were 9 combinations). Participants were then asked to rate the ECA on five personality characteristics, and to assess its persuasiveness and intention to use.

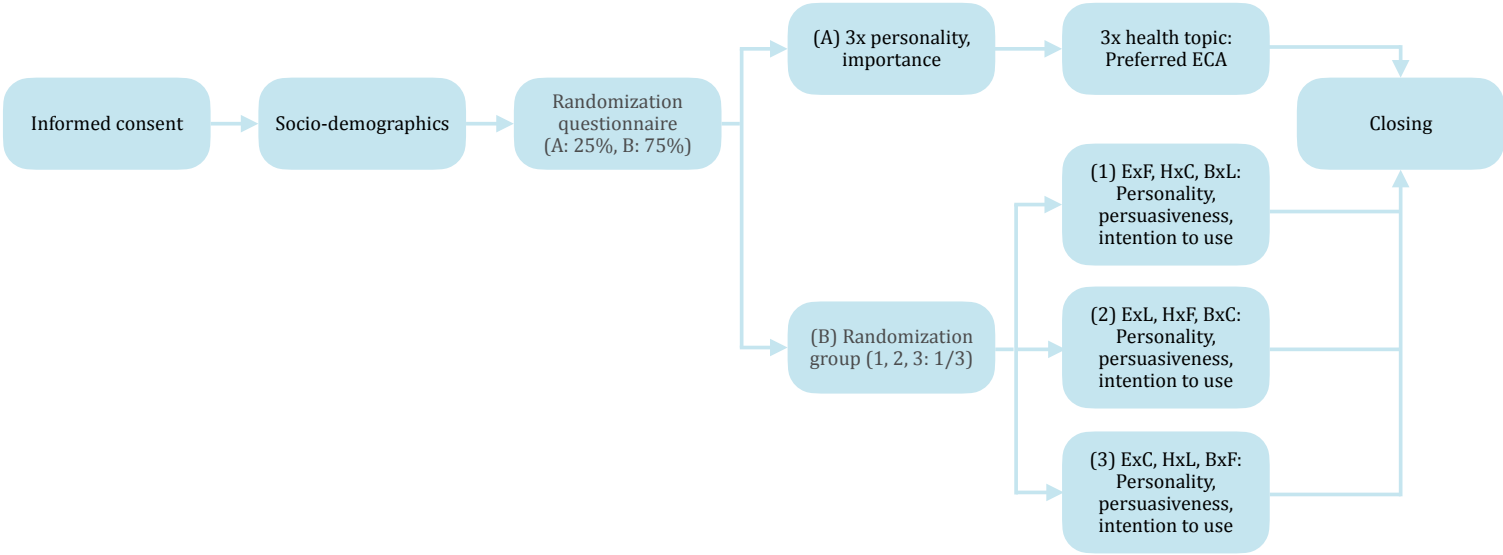

Figure 2: Flow of the questionnaire.
Note: E=Ellen, H=Herman, B=Bo. F=Food, C=Cooking, L=Loneliness.

Measurements

All participants were asked questions about their socio-demographics, including: age, gender, retirement (y/n), highest finished education, living situation (with partner, without partner, with someone else), whether they had home-cooked dinners (y/n) and chronic diseases. In addition, we also measured health literacy, using the Three Brief Health Literacy Screeners [28].

For questionnaire A, participants reviewed the three ECAs without a health topic, or only the health topics. The following data were collected:

- Ratings of the personality characteristics per ECA: friendliness, warmth, trustworthiness, concern and competence. These five characteristics were based on the previous co-creation study. The questions were measured using participant agreement with a 5-point Likert scale ranging from "1 = Strongly disagree" to "5= Strongly agree"
- Ratings of importance of the five personality characteristics. The following statement was provided: "In general, I think it is important for a coach to show the following characteristics". The question was answered on the same 5-point Likert scale.
- Preferred ECA per health topic, after seeing only the health topic. The following question was asked: "Which virtual coach would be able to help you best?" The answer option consisted of an image of each of the three ECAs.

For questionnaire B, participants reviewed three different ECAs, addressing three different health topics. The following data were collected:

- Ratings of the personality characteristics per ECA. The questions were measured using the same 5-point Likert scale.
- Ratings on persuasiveness and intention to comply per ECA. This was measured by a validated perceived persuasiveness scale, adapted from Drozd et al.[29]. The scale consists of four questions: i) "The system would influence me."; ii) "The system would be convincing."; iii) "The system would be personally relevant for me."; iv) "The system would make me reconsider my (eating) behavior. The questions were measured using the same 5-point Likert scale.
- Intention to use, measured via the question "I would like to use this program", and answered on the same 5-point Likert scale.

Data analysis

Data were analyzed using SPSS/WIN 25.0 software (IBM Corp., Armonk, NY, USA). Data are presented as mean $\pm$ standard deviation (SD) for normally distributed continuous variables, and frequencies and percentages for categorical variables. For H1, we first controlled whether all personality characteristics were deemed important ($>$3.0). Next, we generated the average score of the five personality characteristics per ECA, split into with and without health topic, and used the independent t-test to test statistical difference.

For H2 we counted how often an ECA was preferred for a certain health topic, using 40% as a cut-off score to identify a match. In addition, we used ANOVA to test for significant influence of gender or age. For H3, we first created categories for matching and other combinations, and generated a single score for persuasiveness (α was between .915 and .963). We then compared scores on average personality, persuasiveness and intention to use between both categories, using the independent t-test. Normality was assumed based on the sample size. A two-sided p value of < 0.05 was used as the cut off for statistical significance. All calculations were discussed with a statistician. The data underlying this article will be made available at DANS EASY repository [30].

Method focus group

Participants

We invited all thirteen participants from our previous study [27] to participate in this focus group. Invitations were send per mail and post, based on the preference of the participant. In total, six participants signed up and joined the focus group.

Study design

In the focus group we discussed the findings and improved the appearance of the ECA. The duration of the sessions was four hours, including a lunch and one-hour break. The aim of the analyses was to provide deeper insights on the match between the ECA and the health topic, the appreciation of ECAs in terms of positive personality traits, and the persuasiveness of ECAs. More specific:

- How should the appearance of the ECAs be improved?
- How should the personality of the ECAs be designed?

Procedure

As a result of the online questionnaire, two ECAs were selected for the three different health topics. Participants were picked-up at home and we (LK and StS) met at the headquarters of the National Foundation for the Elderly. After a short introduction, participants were asked to provide informed consent. In total, the focus group consisted of three assignments.

During the first assignment, the designer (StS) showed an image of the first ECA, and LK provided a recap of the cooking topic. Participants were asked why they thought this particular ECA was preferred for this health topic. Next, we asked how participants thought the design of the ECA could be improved. When a participant mentioned, for example, the haircut, this was adjusted at the spot and improved until satisfaction was reached. We created a set of design characteristics upfront to ask participants' opinions about, if it had not been mentioned yet (including age, skin color, BMI, outfit, hair, eye color, accessory, other). For the second assignment we asked participants to write a background story of

the ECA and share it afterwards. Next, we repeated the first and second assignment for the other ECA.

During the last assignment, we invited participants in groups of three to write a short dialogue between an ECA and a user. We provided them with post-it notes, and discussed a short general example. They were instructed to write an opening, explain something about PACO, and write an ending. This was repeated for the other ECA. Afterwards, we discussed the dialogues plenary, and created a list of conditions for the dialogues.

Data analysis

Work-sheets were scanned. Audio recordings of the sessions were transcribed verbatim by an independent agency and reviewed by the research team for accuracy by comparing the audio recordings with the written transcripts. Pseudonyms were developed for each participant to maintain confidentiality. All data was uploaded in ATLAS.ti 8. qualitative data analysis software. Analysis was guided by a thematic analysis approach, and combined a deductive and inductive approach [31]. One researcher (LK) created a first list of codes based on the script for the session. Both LK and StS then coded the transcripts independently, and added extra codes if needed. Differences in codes and coded fragments were discussed, leading to a final and agreed upon codebook (see Supplementary materials 4) and coded transcript.

Results

Questionnaire

Characteristics of participants

The questionnaire was filled in by 732 study participants, of which 729 completed the questionnaire online. Five participants only filled in the demographics, and were therefore excluded. The mean age of the 727 study participants was 72.7 $\pm$ 8.11 years, with 83.8% being retired. Women accounted for 62.6% of participants. Half of the participants lived alone (50.5%), other participants lived with their partner (47.7%), or with someone else (1.8%). Almost all participants had home-cooked dinners (91,6%). In total, 52,5% had completed high school or some associate degree, 40.5% of all participants had completed college or university. The mean health literacy score was 6.51 $\pm$ 1.68 out of 12.

Personality characteristics of the ECAs

The descriptive statistics of the importance of the separate personality characteristics show that all characteristics were rated important (score between 3.84 and 4.36, see Table 1 for all details). After controlling for violation of the assumption of sphericity, a repeated measure ANOVA showed that the ECAs were rated significantly different on all five characteristics: friendliness ($F(1,324) = 85.322$, $p < .001$), warmth ($F(1, 324) = 61.459$, $p < .001$), trustworthiness ($F(1, 324) = 174.401$, $p < .001$), concern (F(1,

324) = 70.455, p < .001) and competence (F(1, 324) = 146.948, p < .001). Pairwise comparisons, with Bonferroni correction, reveal that Ellen (the peer) scored significant higher than Herman (the cook) on all characteristics (p < .001 and p = .036), with the exception of warmth (p = .094). Furthermore, Bo (the fantasy figure) differs significantly from both Ellen and Herman on all five characteristics (p < .001).

Table 1: Rating of the importance and personality characteristics per ECA.

Characteristics	Importance	Appreciation per ECA		
	General	Ellen	Herman	Bo
Friendliness	4.06 ± 0.83	3.21 ± 0.98^{A}	3.05 ± 0.96^{B}	2.55 ± 1.14^{C}
Warmth	3.84 ± 0.90	2.94 ± 0.89^{A}	2.82 ± 0.82^{A}	2.40 ± 1.02^{B}
Trustworthiness	4.25 ± 0.88	3.12 ± 0.78^{A}	2.81 ± 0.75^{B}	2.31 ± 0.95^{C}
Concern	4.16 ± 0.89	2.99 ± 0.78^{A}	2.86 ± 0.77^{B}	2.34 ± 0.96^{C}
Competence	4.36 ± 0.90	3.01 ± 0.77^{A}	2.89 ± 0.86^{B}	2.27 ± 0.94^{C}

Note: Statistically significant differences among these means do not share a superscript.

As can be seen in Table 2, Ellen received the highest score for overall personality, both with and without health topic. Results of the independent t-test showed a significant difference on rating of personality characteristics without and with addressing a health topic for Ellen (t(563) = -5.004, p < .001), Herman (t(567) = -7.034, p < .001) and Bo (t(568) = -12.656, p < .001).

Table 2: Average rating of personality characteristics without and with health topic.

	Ellen	Herman	Bo
Without health topic	3.05 ± .69	2.89 ± .70	2.37 ± .92
With health topic	3.35 ± .72	3.29 ± .70	3.26 ± .69
Difference (p)	< .001	< .001	< .001

ECA and health topic

For Cooking and Food, Herman was the preferred ECA (72.3% and 45.3% respectively, see Table 3). For Loneliness, Ellen was preferred (60.5%). Thus, Bo was not the ECA of choice for any of the three topics. There was no significant effect of gender (p was between .153 and .650) or age (p was between .243 and .892).

Table 3: Preferred ECA per health topic

	Ellen	Herman	Bo
Cooking	64 (22.7%)	204 (72.3%)^{A}	14 (5.0%)
Food	107 (41.1%)^{A}	115 (45.3%)^{A}	32 (18.0%)
Loneliness	141 (60.5%)^{A}	50 (21.5%)	42 (18.0%)

Note: A superscript indicates a match.

Effect of a match

As can be seen in Table 3, the match category consisted of Herman for Food, Herman for Cooking, Ellen for Food, and Ellen for Loneliness. The other category consisted of Herman for Loneliness, Ellen for Cooking, Bo for Food, Bo for Cooking, and Bo for Loneliness. Results of the independent t-test showed no significant difference for personality ($t(417) = 1.833$, $p = .068$), but a significant difference for persuasiveness ($t(417) = 3.264$, $p = .001$), as well as intention to use ($t(417) = 3.046$, $p = .002$).

Table 4: Difference between match and other on personality, persuasiveness and intention to use.

	Match	Other	Difference (p)
Personality	3.35 ± .64	3.24 ± .66	.068
Persuasiveness	2.78 ± .95	2.49 ± .92	.001
Intention to use	2.77 ± 1.02	2.46 ± 1.05	.002

Focus group

Link to previous study and characteristics of participants

Based on the online experiment, Ellen was chosen as the ECA for the health contexts Food and Loneliness. Herman was chosen as the ECA for the health context Cooking. The mean age of the six study participants was 83.5 ± 7.71 years. Figure 3 shows the setting of the focus group. According to participants in the focus group, Ellen was chosen for these modules because of her competency. Participants also assumed that she knew some things of food, and that she was easy to approach. Herman was chosen for cooking because he 'had studied for it'. Participants also assumed he was familiar with food for older adults.

Figure 3: Setting of the focus group.

Improving the design

In general, participants were quite positive about Ellen. They agreed she had a 'nice, open and friendly face'. A first suggestion was to broader her neck, and make her eyebrows bigger. Also, her shadow should be less visible. There was an extensive discussion about her glasses. Some participants thought they were too 'fussy' or 'too serious'. While other participants thought they looked nice. In the end we agreed to change the color of the frame, so it was less remarkable. Figure 4 displays Ellen before and after the focus group.

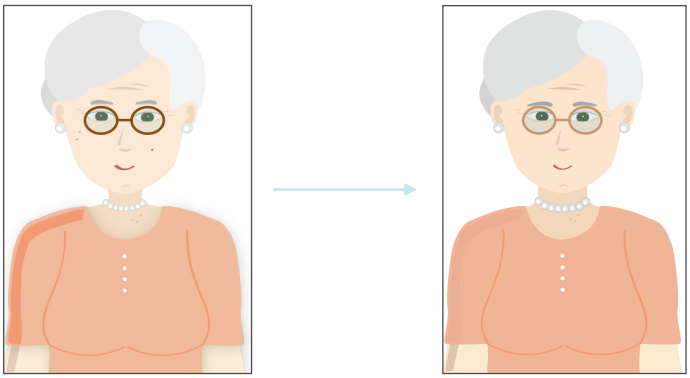

Figure 4: Ellen before and after the focus group.

Participants thought Herman had the right age. This was extensively mentioned by one of the participants as following:

"I choose a young cook who just left the cooking school, or where does he come from. Know the last things, be aware of the possibilities that are available (...). An old cook does not know all that exactly, and a young man does."

Participants further agreed the mustache should be smaller, but was a nice addition. His shirt should indeed be white, without any stains, and he should wear a traditional chef's heat. Figure 5 displays Herman before and after the focus group.

Personality

Although the background stories written for Ellen were different from each other, the general line was rather similar. Ellen is a person with some life experience, a loving person, and has a family and multiple children. She is easy to feel at home with. An example of a story is the following:

"Ellen, a familiar appearance, loves people, a people person, has great colleagues, does this work from her heart, enjoys the work but not too many hours. Because otherwise she gets upset and you get another Ellen. Has a good home base, time for her family, a sweet husband. She is a good listener with empathy. Does she have a nice hobby, nice family, dear husband, I already said that-"

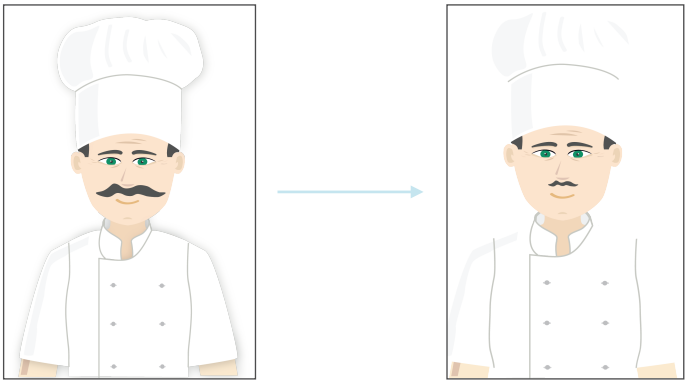

Figure 5: Herman before and after the focus group.

Herman is a nice and fun person, who loves to eat, and is a bit overweight. He loves to eat nice food, and is always busy with work. Multiple participants also wrote that he played soccer in his free time, and again, is competent.

"My cook should be a pleasant person. He likes good food, but together. Because he often stands alone in the kitchen and then has to taste everything. It makes him fat. So that actually belongs to a cook. The advantage is also that he is married so that his projects can be criticized. How would the cook be at home? Does he cook there?"

During the writing process of the dialogues, various requirements were discussed. There were personal differences, especially regarding the formality of the tone. The following requirements stood out:

Table 5: Requirements and example quote.

Requirements	Example quote
Use short sentences	"Good day sir, may I introduce myself? I am Ellen the food coach, sent by your doctor, Dr. P. I'm going to give a short explanation about the food project."
Include small talk	"How are you?"
Allow user to tell about their own life	[user] "I try to eat healthy, but I do not always succeed." But also, off-topic: "Car got rid of, you shouldn't change sixty years of damage-free driving."
Ask user which name to use	"Can I say Annie?"
Use a formal tone	"Good day sir or madam?"
Adjust greeting on time of day	"Good morning.."
Provide the user with choice	"We have an app for cooking, food and loneliness. Would that be something for you?"
Provide suggestions for activities and details	[Ellen] "..but you may enjoy meeting other people in the community center from time to time..." [user] "And then I ask how it works and how much it costs I always ask. And then she tells you how it works and how much it costs."

Discussion

This study investigated whether a match between the health topic and an ECA was associated with a more positive evaluation on five personality traits, persuasiveness and intention to use. The results reveal that older adults prefer an ECA that has an appearance matching a certain health topic, resulting in higher ratings on persuasiveness and intention to use. Positive personality traits are not appreciated better as a result of a match. However, we found that it is important to measure these traits embedded in a health topic in order to gain a realistic rating for when the ECA is used in practice. In a focus group we explored how both design and personality evaluations should be further improved. Multiple specific design changes were made, and we developed two background stories and a list of requirements for the tone of voice in the dialogue script.

Match with health topics

Our results show that a match between the appearance of an ECA and its health topic is preferred by end-users over a non-match. These findings are in line with a large body of literature that uncovered the effects of appropriate appearances by healthcare professionals. For example, Hatfield and colleagues [32] concluded that a standardized uniform increases perceptions of professionalism and recognition among patients. Their conclusion may also explain our findings. However, we also found that a match between ECA and a health topic did not positively effect the appreciation of the ECA personality. It was expected that, by matching appearance with a health topic, the positive aspects of stereotypes can be used, thereby boosting the end-user's judgment of personality traits that are typically favored for a specific stereotype. For the case of an informative website about cancer screening, a match between health information design and stereotypes was shown to lead to increased message credibility and informativeness and positively effects the attitude towards cancer screening [33]. The authors explained these effects via the social judgment theory [34]. The theory posits that when people are confronted with new (sources of) information, they relate this to their current knowledge or attitudes (in this case, stereotypes). If their previous conceptions are confirmed, their appreciation of this new source is higher, and vice versa. So, when the appearance of an ECA confirms with the end-users' initial, stereotypical conceptions, given the health topic, the persuasiveness of the ECA will increase, but not necessarily the appreciation of its personality.

ECA personality

In line with previous studies [25–27], our results confirm that the traits friendliness, warmth, trustworthiness, concern, and competence, are all deemed important for an ECA. However, when only provided with an image of an ECA, people rate them differently. Thus, without considering a health topic, we found that people rated the personality traits of a peer higher than those of a cook, and the personality traits of a cook higher than those of a fantasy figure. Earlier review on ECAs in the health context already showed that fantasy figures are not often used [6], and show that human agents are generally preferred over

cartoon-like agents [6, 10]. When a health context is provided, and thus dialogue is added in the form of a mock-up, it becomes evident that the personality traits of all three ECAs are rather higher, and that the order of preference remains consistent. This finding that people appreciate personality traits higher when provided with dialogue can be explained by the fact that personality is reflected in dialogue. Kampman et al. [35] proposed a neural network based fusion method, and showed that personality traits of ECAs are best predicted when audio, language and appearance are combined. This indicated that it is indeed important to consider the tone of voice, when writing dialogue for a specific ECA. In our results we provided various requirements, and argued to include disclosure. Revealing information makes people likable to others, we disclose more to those we like, and we like others we have disclosed to [36]. This general rule for humans, is also proven to be true for ECAs [6, 20]. Following the golden standard when designing ECAs for health, a background story and tone of voice is best created together with the potential end-user in order to increase the changes of higher use and greater effect [6].

ECA persuasiveness

The ECAs were perceived as more persuasive with than without a health topic. Thus, they were perceived as more influencing, convincing, relevant, and made them reconsider their behavior more. Furthermore, the intention to actually use the ECA also increased when the health topic was shown. However, one should aim to increase the persuasiveness of an ECA, rather than simply measure it. We asked end-users for their preferences regarding the appearance, and thereby aimed to tailor the design of the ECA further to the needs and wishes of community-dwelling older adults. The overview of design principles created by Oinas-Kukkonen and Harjumaa [22] was not intended to use as a checklist, but rather to select the principles most important for the system at hand. For ECAs in the health context, these seem to include tailoring and similarity, in the form of offering relevant suggestions and a background story similar to that of a potential user. With regard to the personality of the ECA, both trustworthiness and expertise are important design features. Last, we showed that the social role should be matched to the health context. Incorporating these design features, increases the changes for adherence, and maximizes the changes of actual health behavior change.

Limitations of the study

Our results show the preference of Dutch community-dwelling older adults towards the appearance and personality of various ECAs in the health context. Among other things, this includes the preference of a humanoid ECA over a fantasy figure. However, earlier studies show that certain preferences are clearly context dependent, and differ from person to person. Hence, our findings are not simply generalizable to curative interventions where the focus might be on other personality traits or design features. Furthermore, it is known that older adults have other preferences regarding ECAs compared to youngsters [20]. Thus, research outside the context of health ECAs for older adults, should always consider

tailoring their ECA to their specific target group. We hope to have offered a method to do so.

Another limitation which should be taken into account is the setting of the study. During the questionnaire, we asked participants to rate the ECAs after an initial and single interaction. These results might be different if participants were exposed to the ECA for a longer period of time. Hence, one should ideally retake these questionnaires in the evaluation process of the ECA to make sure the suggested design guidelines still remain valid.

Concluding remarks

In this article, we have uncovered design guidelines for developing ECAs within the health context, with a particular focus on a match between the ECA and the health topic, ECA personality, and ECA persuasiveness. Since more engaging means of communication are rapidly taking over the text-based information which was favored in healthcare for so long, it is an important task for the human-computer interaction community to develop guidelines that can aid the visual and dialogue design of this modality. Our efforts have completed a part of the puzzle. It is now up to future studies to develop further guidelines and complete it.

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Chapter 5

Use and effect of web-based embodied conversational agents for improving eating behavior and decreasing loneliness among community-dwelling older adults: Protocol for a randomized controlled trial

Abstract

Background: An unhealthy eating pattern and loneliness negatively influence quality of life in older age. Embodied conversational agents (ECAs) are a promising way to address these health behaviors in an engaging manner.

Objective: We aim to (1) identify whether ECAs can persuade community-dwelling older adults to change their dietary behavior and whether ECA use can decrease loneliness, (2) test these pathways to effects, and (3) understand the use of an ECA.

Methods: The web-based eHealth service PACO is a fully automated 8-week intervention in which 2 ECAs engage older adults in dialogue to motivate them to change their dietary behavior and decrease their loneliness. PACO was developed via a human-centered and stakeholder-inclusive design approach and incorporates Self-determination Theory and various behavior change techniques. For this study, an unblinded randomized controlled trial will be performed. There will be 2 cohorts, with 30 participants per cohort. Participants in the first cohort will immediately receive the PACO service for 8 weeks, while participants in the second cohort receive the service after a waiting-list condition of 4 weeks. Participants will be recruited via social media, an online panel, flyers, and advertorials. To be eligible, participants must be at least 65 years of age, must not be in paid employment, and must live alone independently at home. Primary outcomes will be self-assessed via online questionnaires at intake, control, after 4 weeks, and after 8 weeks, and will include eating behavior and loneliness. In addition, the primary outcome—use—will be measured via data logs. Secondary outcomes will be measured at the same junctures, via either validated, self-assessed, online questionnaires or an optional interview.

Results: As of July 2020, we have begun recruiting participants.

Conclusions: By unraveling the mechanisms behind the use of a web-based intervention with ECAs, we hope to gain a fine-grained understanding of both the effectiveness and the use of ECAs in the health context.

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Introduction

Background

Unhealthy eating and loneliness negatively influence quality of life (QoL) in older age [1, 2]. Statistics show that in the Netherlands, almost 60% of people over 65 are obese [3], and 57% of community-dwelling older adults are at risk for undernutrition [4]. Both are important risk factors for chronic diseases and are clearly associated with unhealthy eating behaviors. As eating is regarded a social activity, loneliness is associated with a loss of pleasure in eating and cooking [5] and is a significant predictor of malnutrition [6]. Loneliness can be defined as the discrepancy between a person's desired and achieved levels of social relationships [7]. In the Netherlands, over 50% of older adults indicate that they experience loneliness, a percentage that is even higher among people without a partner [8]. The expected increase in the coming years [9] in this group of single, community-dwelling older adults will exacerbate this problem. However, it is challenging to realize an actual change in eating behavior and deal with loneliness.

Embodied conversational agents (ECAs) have been proposed as a promising technological tool to persuasively address these health behaviors, with the aim of changing users' attitudes or behaviors through persuasion and social influence rather than through coercion [10]. ECAs can be defined as "more or less autonomous and intelligent software entities with an embodiment used to communicate with the user" [11]. A typical user interface consists of a human-like ECA with prewritten dialogues, including multiple choice answer options [12]. ECAs can make an intervention for coaching people in a healthy lifestyle more engaging than traditional electronic health interventions [12]. This ability is often ascribed to ECAs' capacity to establish and maintain an emphatic relationship [12, 13]. Early studies show that older adults who interact with an ECA form a relationship with the ECA and consider it a companion [14], including those from populations in which eHealth literacy is generally lower [15]. ECAs are perceived as enjoyable, usable, and acceptable for addressing health behavior change [16–18].

Nonetheless, interventions with an ECA are not immune to declining use over time, meaning that this issue must be addressed in ECA design to prevent limited long-term health effects [12]. Furthermore, and even more importantly, evidence of ECA effectiveness and underlying working mechanisms is scarce and remains inconclusive [12]. This limits the possibility to learn from others' efforts and prevents knowledge accumulation.

Objectives

We present the protocol for an 8-week evaluation of the PACO service. Consisting of 2 ECAs, PACO is a web-based service that aims to achieve dietary behavior change and decrease loneliness among single, community-dwelling older adults. The goal of the evaluation is to (1) identify whether ECAs can persuade community-dwelling older adults to change their dietary behavior and decrease their loneliness, (2) assess the pathways to effects, and (3) understand ECA use. The latter 2 goals will allow us to explain the

occurrence (or the lack) of an effect from using the intervention and can therefore serve to support the design of future ECAs.

Conceptual Models

In order to conceptualize and measure engagement, Cole-Lewis et al [19] state that it is necessary for users to have appropriate levels of interaction with the technology and that the behavioral change components are relevant. Hence, we present 2 conceptual models (see Figure 1). The first is a conceptual model explaining ECA use (CEU). With this model, we aim to explain the factors that determine the use of an ECA intervention in this context. The second is a conceptual model explaining health effects (CHE). With this model, we aim to explain the mechanisms behind the observed change in eating behavior and loneliness.

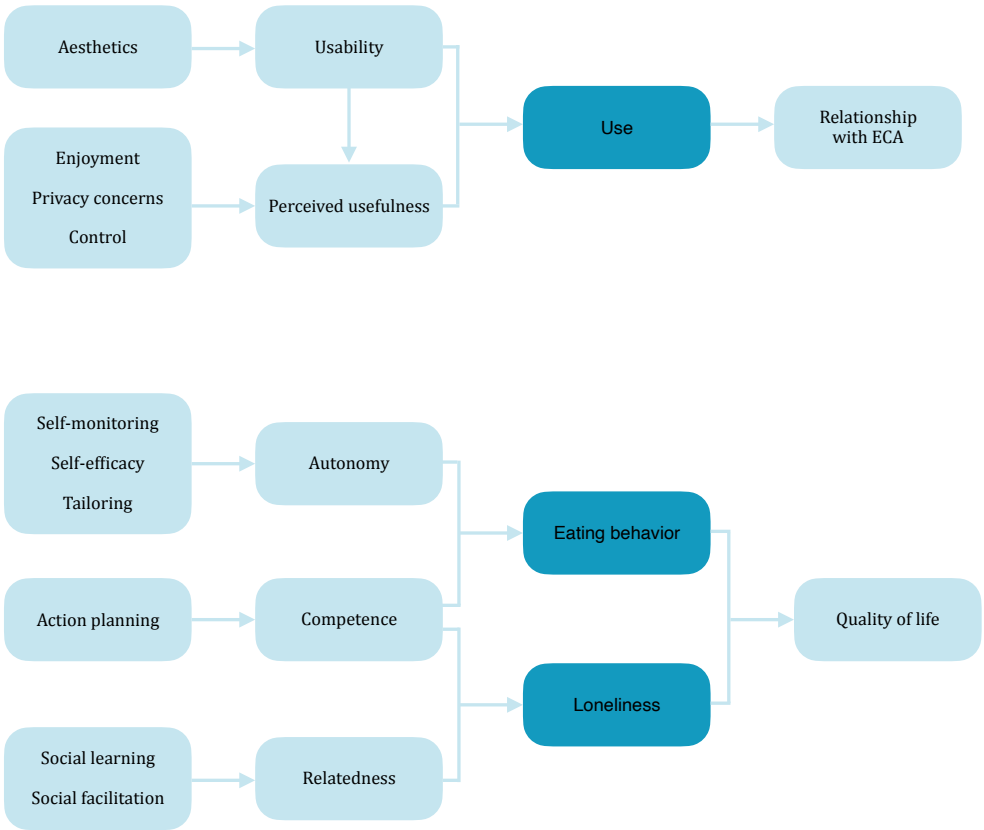

Figure 1: Conceptual model explaining ECA use and Conceptual model explaining health effects.

Use is at the center of the conceptual model explaining ECA use. It is assumed that an eHealth intervention will not be used if it does not create any benefit (perceived usefulness)

or if it has a substantial number of usability problems [20]. Visual aesthetics, defined as an orderly and clear design, are closely related to many of the design rules advocated by usability experts [21]. In the case of patient portals, aesthetics have thus been found to influence usability in the context of explaining technology acceptance [22]. We expect perceived usefulness to be influenced by 3 user experience factors. Perceiving something as enjoyable is linked to a positive effect on use when the system is perceived to be useful [23]. Willingness to share personal information and preferences (ie, the absence of privacy concerns) is argued to be a prerequisite for convenience and a useful system [24]. The last factor is control, which refers to "the extent to which the user can bring about or prevent particular actions or states of the system if she has the goal of doing so" [25]. Especially in human-computer interaction literature, control has been identified as a crucial factor in the occurrence of perceived usefulness and use [26, 27]. Furthermore, there is robust evidence that usability has a direct effect on perceived usefulness [28]. In turn, use is hypothesized to act as an antecedent of the intensity of an end user's relationship with an ECA [14].

Self-determination Theory (SDT) comprises the basis of the conceptual model explaining health effects [29]. Briefly, SDT postulates that human beings have 3 essential psychological needs: autonomy (the feeling of being the origin of one's own behaviors), competence (feeling effective), and relatedness (the need to feel belongingness and connectedness with others). Self-monitoring and self-efficacy are associated with increased autonomy [30]. Tailoring is a more generic behavior change technique (BCT), which, in our case, refers to a tailored recipe book. We hypothesize that the possibility of generating a tailored recipe book leads to an increased feeling of being in control. Action planning is found to be supportive of increasing competence [31]. Both social learning and social facilitation are expected to lead to an increase in relatedness, as they both connect people. In turn, a decrease in loneliness and an improvement in eating behavior is expected to lead to more positive health-related QoL outcomes [1, 2].

Research Questions

Our research questions focus on both use and health outcomes. The research questions related to use are as follows: (1) What factors affect the use of the ECA? (2) Does use affect the users' relationship with the ECA? (3) What is the use of PACO over time? (4) How do users experience PACO use? We will test the CEU to answer research question (RQ) 1 and 2. Via data log analyses (RQ3) and interviews (RQ4) we aim to explain the findings related to the CEU. This way, we will triangulate results.

The research questions related to health effects are as follows: (1) To what extent does PACO reduce loneliness and improves eating behavior and, ultimately, QoL? (2) To what extent does PACO increase autonomy, competence, and relatedness? (3) How does PACO use affect the loneliness and eating behavior of older adults? We will test the CHE to answer RQ1. For RQ2 and RQ3, we will compare the effect of using PACO at different time points, including control.

Methods

Study Design

An unblinded randomized controlled trial will be carried out. At the time of study protocol submission, all preparations have been made to start recruitment. There will be 2 cohorts (Figure 2). Participants in the first cohort will receive the 8-week PACO service immediately. Participants in the second cohort will receive PACO after a 4-week waiting-list condition and serve as a control group. A combination of various data collection methods will be used for this study, including questionnaires (control, at intake, T0, T1, and T2), data log collection during the intervention period, and an optional interview afterward. The T0 questionnaire will mark the start of the intervention, T1 will be completed after 4 weeks of use, and T2 after 8 weeks of use (Figure 2).

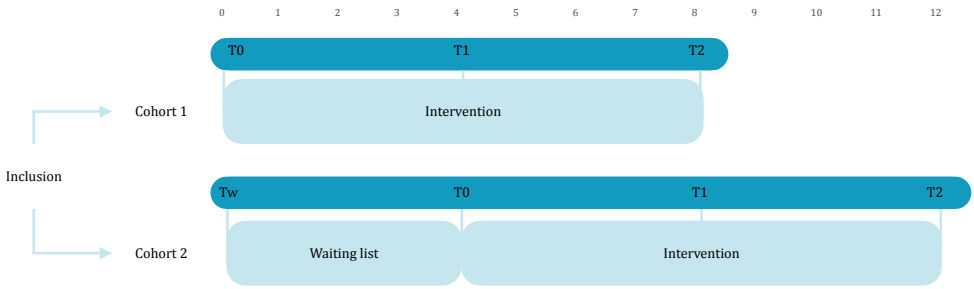

Figure 2: Study design.

Participants

We aim to include a total of 60 participants: 30 in cohort 1 and 30 in cohort 2. The number of participants is based on the 10-times rule, a widely used minimum-sample-size estimation method for partial least squares structural equation modeling (PLS-SEM) [32]. This method was discussed with a statistician. In addition, we considered the current practices in the field [12], the explorative nature of this study, and the staff available to provide support.

Participants will be considered eligible if they are aged 65 years or older, are not in paid employment, and live alone independently at home. These inclusion criteria fit a potential target audience of almost 1 million people [33]. In addition to these criteria, participants need to speak Dutch to use the service, should be able to use a tablet or computer by themselves, and should have a wireless internet connection at home, which is required for the service. The latter 2 criteria seem feasible, as 94.5% of all older Dutch adults aged 65-75 years have internet access at home, with 77% using the internet daily [34]. Apart from willingness to provide informed consent, there are no exclusion criteria.

Recruitment

The project members will recruit participants via different routes. An email will be sent out to an existing online panel of older adults (Ouderenpanel). Flyers will be distributed in neighborhoods, community centers, sports canteens, and other settings frequently attended by older adults. Advertorials will be placed in local and community newspapers and on social media. Both the flyers and the advertorials will contain a short link to the PACO website with more information and the form to sign up. Lastly, participants will be encouraged to invite relatives.

Procedure

Interested people can visit a website to view more information, or they can contact the researchers. People can choose to receive the information letter and consent form by post or view and complete the form online. After providing informed consent, participants will be invited to complete the intake questionnaire. In this questionnaire, they will be asked to report their demographics (gender, age, educational level, health conditions, risk of malnutrition [35], and eHealth literacy [36]), whether they own a device to use for the study, and their motivation to participate. A copy of the signed informed consent will be sent to all participants by mail. The researchers will mail people who do not return the informed consent by post to check whether something has gone wrong or they do not wish to participate (no explanation will be required). After completing both the informed consent and the intake questionnaire, participants will be assigned a random 4-digit research number. To allocate participants to a cohort, they will be randomly assigned a digit, either 1 or 2, in a list generated by Excel (version 16.0.13426.20274; Microsoft). Participants will receive an email from author LK containing their research number, information on their allocated cohort, and a copy of the information letter and the signed informed consent.

Participants in cohort 2 will first be asked to complete the additional control questionnaire (Table 1) and will start the intervention period after 4 weeks. At the start of the intervention period, participants will receive an email with instructions for the onboarding process. The email will contain a video message from the researchers introducing themselves and the project, as well as a link to the freely available PACO website. Once participants have created an account, they will be asked to complete the T0 questionnaire, assessing the health parameters and relationship with the ECA. Participants will be phoned within 2 working days and asked whether they have any questions. If a participant does not wish to be called, this can be indicated by email. If a participant needs help, the researchers will offer to visit the participant. A logbook will be kept of all such contacts. If participants do not have a tablet or a computer, they will be given a tablet for the duration of the study.

After 4 weeks of use, participants will receive an email with an invitation to complete the online T1 questionnaire, assessing all their health factors, their relationship with the ECA, and their user experience. After 8 weeks of use, participants will receive an email

Table 1: Metadata and factors measured via questionnaires, per study phase.

Metadata and factors	Questionnaires			
	Control	T0	T1	T2
Metadata questionnaire				
Total number of questions, n	46	56	65	88
Minutes to complete	10-20	15-20	15-20	25-30
Conceptual model explaining health effects				
Eating behavior	-	-	-	-
Loneliness	-	-	-	-
Autonomy, competence, and relatedness	-	-	-	-
QoL	-	-	-	-
Conceptual model explaining ECA use				
Relationship with ECA		-	-	-
Usability				-
Enjoyment				-
Aesthetics				-
Privacy concerns				-
Control				-
Perceived usefulness				-
Other constructs				
User experience			-	
Willingness to pay				-

with an invitation to complete the T2 questionnaire, assessing all their health and use factors and willingness to pay. In addition, participants will be asked whether they are open to an interview lasting half an hour, in which the researcher will ask about their user experience.

At all stages of the study, participants will be able to contact the researchers by email or phone for any questions or problems. In PACO, there is a contact form. Depending on the participant's problem and preference, one of the researchers will email, phone, or visit the participant. If a participant has not interacted with PACO for 7 days, the participant will also be contacted and asked whether there are any problems.

Intervention

PACO

PACO is a fully automated web-based eHealth service in which 2 ECAs engage in dialogue with older adults in order to motivate them to change their dietary behavior and decrease their loneliness (Figure 3). The service consists of 5 modules, each one applying different BCTs (Table 2). During the onboarding process, the ECAs introduce themselves and explain the PACO program. There is a daily dialogue between either Herman (the cook, who provides nutritional advice) or Ellen (the peer, who provides social advice) and the

user. Users are asked to use the food diary module for the first 7 days in order to increase their awareness of their eating behavior. All other modules become available when the food diary has been completed for 7 days or automatically after 14 days. During and after the 8-week program, the ECAs encourage users to continue the health behavior changes that they have implemented during the intervention in their daily lives.

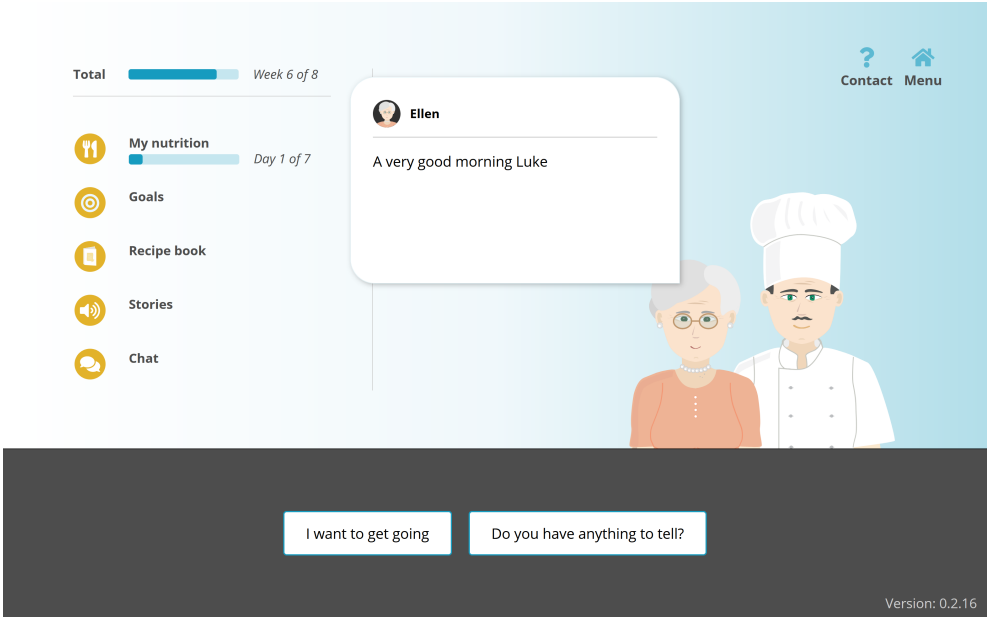

Figure 3: The PACO service.

Development of the Intervention

The PACO development process was based on the first 3 steps of the Center for eHealth Research and Disease Management (CeHRes) Roadmap [43]: the contextual inquiry, the value specification, and the design phase. The contextual inquiry phase consisted of 3 parts. First, the current practices in designing and evaluating ECAs for coaching people in the health context were identified via a scoping review [12]. Second, factors contributing to healthy living and healthy and unhealthy eating among Dutch community-dwelling older adults were identified via a 7-day diary and via multiple focus groups [44]. Third, an initial stakeholder analysis was carried out, and key stakeholders were identified [45].

During the value specification phase, healthy eating tips were explored via 2 additional focus group sessions [44]. The preferred approach, source, and tone of voice for healthy eating tips were discussed. In addition to the focus group, interviews were held with key stakeholders in order to identify their requirements [45].

The design phase of PACO was based on the previous 2 phases. In addition, the SDT [29] was used as a foundation. Self-monitoring, action planning, tailoring, self-efficacy, social

Table 2: The modules of the PACO service.

Week	Module	BCT	SDT component, target behavior	Rationale
1	Food diary	Self-monitoring	Autonomy, eating behavior	Users record what they have eaten, with whom, and how they appreciated the meal. There is an option to set reminders. When users know what they eat and drink, we aim to give them the feeling that they are able to change their behavior [37], leading to an actual change in eating behavior.
2-8	Goals	Action planning	Competence, eating behavior and loneliness	Users can choose from a list of social and eating goals. Via dialogue, Ellen explains the goal and provides tips. Users create a personal action plan and track their progress, with the option to set reminders. When users carry out their plans, we aim to improve their feelings of competence [31], leading to changes in eating behavior and feelings of loneliness.
1-8	Recipes	Tailoring and self-efficacy	Autonomy, eating behavior	Via dialogue, Herman helps users select a healthy and easy-to-prepare recipe (>280), based on users' dietary wishes and preferences. By assisting users in cooking their own meals in line with their preferences, we hope to increase feelings of autonomy via self-efficacy [38], leading to a change in eating behavior.
1-8	Stories	Social learning	Relatedness, loneliness	Users can listen to stories from other older adults about physical or virtual social activities they perform. Ellen can provide more information on the activity. When users learn from each other, we hope that they will feel more related to others and have fewer feelings of loneliness [39, 40].
1-8	Chat	Social facilitation (peer support)	Relatedness, loneliness	Via WhatsApp groups, users can interact with one another. Ellen is also included and asks questions. When users interact with one another, we hope that they will experience increased feelings of relatedness and decreased feelings of loneliness [41, 42].

learning, and social facilitation were selected as BCTs. In the design phase, first, 3 ECAs were created, each with a different role. In order to ascertain their persuasiveness, an online experiment using various mockups was carried out. Via a focus group, the findings were discussed, and the layout of the 2 preferred ECAs was improved. All input was used

to create a first version, which was tested via a usability study [46]. All usability issues were resolved, leading to the final eHealth service.

Data Collection

The main study parameters include use, eating behavior, and loneliness. Use will be assessed via data logs, which will be collected by the PACO service. More specifically, data logs contain the user ID, timestamp, dialogue, and ECA (either Ellen or Herman). In addition, data logs contain the number of goals achieved, the diary input, and the chat history. Eating behavior will be self-assessed by 3 open questions, based on a 24-hour recall format. The questions include the following: (1) Did you eat fruit yesterday? If so, what kinds of fruit, what time, and how many grams per piece? (2) Did you eat vegetables yesterday? If so, what kinds of vegetables, what time, and how many grams per piece? (3) Did you drink yesterday? If so, what kinds of drink, what time, and how many glasses, cups, or milliliters? Loneliness will be self-assessed via a questionnaire (Table 3).

Table 3: Details of the questionnaires.

Factor	Questionnaire	Items, n	Scale	Modifications
Loneliness	De Jong Gierveld Loneliness Scale [47]	6	1-5	None
Autonomy, competence, and relatedness	Basic Psychological Need Satisfaction and Frustration Scales [48–50]	24	1-5	None
QoL	Brief Older People's Quality of Life [51]	13	1-5	Translated to Dutch
Relationship with ECA	Rapport Scale [52–54]	10	1-5	Translated to Dutch; 'virtual coach' instead of 'coordinator'
Usability	System Usability Scale [55]	10	1-5	Translated to Dutch
Enjoyment	Affect Scale [56]	4	1-5	Translated to Dutch
Aesthetics	Classic Aesthetics [21]	5	1-7	Translated to Dutch
Privacy concerns	Concern for Privacy Scale [24]	4	1-7	Translated to Dutch
Control	Active Control [57]	4	1-7	Translated to Dutch; 'PACO' instead of 'website'
Perceived usefulness	Perceived Usefulness Scale [28, 58]	3	1-5	Translated to Dutch; 'PACO' instead of 'the robot'

The secondary study parameters include self-determination (autonomy, competence, relatedness), QoL, relationship with ECA, usability, enjoyment, aesthetics, privacy concerns, control, and perceived usefulness. All these parameters will be measured via validated, self-assessed, online questionnaires.

In addition, 2 other parameters include willingness to pay and user experience. Both parameters will be assessed via self-compiled questionnaires. Participants will be asked

whether they are willing to pay for PACO (yes/no) and the amount they are willing to pay for PACO for 3 months [€0, €5 (USD $6.09), €10 (USD $12.18), or €20 (USD $24.35) per month]. Via a questionnaire, participants will be asked 9 open-ended questions about their user experience in general (eg, How did you experience using PACO the last 4 weeks?) and per module (eg, Which modules did you perceive as useful, and why?). In addition, participants will be asked why they kept using PACO, why they stopped using PACO, and whether they wish to share something else. Via an interview of approximately 30 minutes, participants will be asked about their general experience, the modules, how and where they used PACO, experienced behavior change, and the two coaches. Via these questions, we aim to gain a more fine-grained understanding of users' experiences and triangulate our quantitative results.

Data Analysis

Descriptive statistics will be used for participant demographics, data logs, and willingness-to-pay data. Data logs will be used to determine the frequency of login, time spent on each module, time spent in total, time of use, and time of dropout. If a participant has not interacted with PACO for 14 consecutive days, they will be treated as a dropout and omitted from further analysis. The within-subject t test will be used to compare effects between control, T0, T1, and T2. PLS-SEM will be used in 2 phases per model to test the conceptual models. In phase 1, the measurement model will be validated by testing the constructs separately to determine internal validity [using structural equation modeling (SEM)-oriented criteria and a traditional Cronbach alpha]. In addition, it will be determined whether there is multicollinearity. If there is an acceptable measurement model, phase 2 will be carried out. The causal model will be tested and, if necessary, optimized. A conservative approach will be adopted whereby the theoretical model will be adjusted only if this results in a large improvement in the model. The quality of the causal model will be determined on the basis of PLS-SEM specific goodness-of-fit indices. All analyses will be performed in SPSS (version 24; IBM Corp) and SmartPLS (version 3; SmartPLS GmbH).

Audio recordings of the interviews will be transcribed until data saturation is reached. The transcripts of, and answers to, the open user-experience questions will be uploaded in ATLAS.ti qualitative data analysis software (version 8.4; ATLAS.ti Scientific Software Development GmbH). Analysis will be guided by a thematic analysis approach [59], combining a deductive and an inductive approach. The protocol for the focus group will be used to generate deductive codes. An initial list of inductive codes will be generated by LK and supplemented independently by another researcher. Differences will be discussed, leading to a final and agreed upon codebook. Each transcript will be coded by LK and another project member. Differences will be discussed again, leading to a final coded transcript.

Ethical Considerations

The study has been approved by the medical ethical committee of Wageningen University (number NL73121.081.20) and has been registered at ClinicalTrials.gov before the enrolment of participants (identifier NCT04510883). As participants are not exposed to any risks, a data safety monitoring board will not be used during the study. Participants will invest time in this study; they have to complete multiple surveys and use the PACO service for 8 weeks. We believe that this duration and data collection are needed to gain a fine-grained understanding of the service's use, relationship development, and the process of health behavior change. The main benefit to participants is that they gain insight into their health behavior via the PACO service. In addition, in prior studies, we found that participants highly appreciate the attention given to them via such studies.

Prior to the study, people will receive an information letter. They will have 2 weeks of consideration time and can contact the researcher (LK) or an independent expert with any questions. Participants can leave the study at any time for any reason if they wish to, without any consequences; participants will not be replaced.

All collected data will be kept in secure online databases that are password-protected, with access limited to the study team.

Results

As of July 2020, we have begun recruiting participants.

Discussion

Overview

ECAs seem to be a promising means of addressing health behavior change in general, including among community-dwelling older adults. In this paper, we have described the protocol for an unblinded randomized controlled trial among older adults, with the goal of understanding the use and health effects of ECAs that provide nutritional advice. The intervention at the center of this evaluation is called PACO and provides 2 ECAs, one that offers nutritional advice (a cook) and one that offers social advice (a peer). The intervention was developed via a human-centered and stakeholder-inclusive design approach, incorporating theory and various BCTs. At the time of writing, evidence on the effectiveness and underlying working mechanisms of ECA use for health purposes remains inconclusive [12]. In order to explain the effects (or the absence thereof), we developed 2 conceptual models. The first model explains the use of an ECA intervention, and the other explains the mechanisms behind the observed change in eating behavior and loneliness after using an ECA intervention. Via the randomized controlled trial, both models will be tested, and use, user experience, and potential health effects will be assessed. In this way,

we aim to generate insight into the effect and design of ECAs that go beyond the PACO service and that serve the eHealth community in general [60].

Limitations

Like any evaluation plan, ours has some limitations. The first limitation relates to our recruitment strategy. We expect to include more women than men. In previous studies [44], we found women to be more interested in lifestyle-related studies, resulting in focus group sessions with an overrepresentation of women. However, given that there are more single women than men in older age groups in the Netherlands [61], a majority of women is a realistic reflection of society. Another aspect of our recruitment strategy is that participants are encouraged to invite relatives, and this might induce a risk of contamination. If a closely related person joins the study, we will monitor this meticulously to see whether contamination takes place, and whether and how it influences our results.

Second, use of the ECA intervention might be influenced by the study itself. Participants know that they are expected to complete multiple questionnaires and will be called by phone if they do not use the service for 7 days. Thus, participants might be inclined to use the service more often than if the intervention were applied outside a randomized controlled trial setting. However, in order to understand the determinants affecting use and health effects, the questionnaires are essential, and a phone call is needed to ensure that there are no technical issues influencing use.

Conclusions

By unraveling the mechanisms behind the use of a web-based service that offers 2 ECAs, we hope to gain a fine-grained understanding of both the effectiveness and the use of ECAs. These insights will boost the design, the use, and the usefulness of ECAs in health behavior change.

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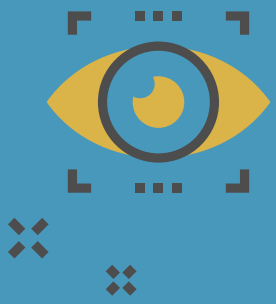

Chapter 6

Use and effect of embodied conversational agents for improving eating behavior and decreasing loneliness among community-dwelling older adults: A randomized controlled trial

Abstract

Introduction: Embodied conversational agents (ECAs) have been proposed as a promising interaction modality for the delivery of programs focused on promoting lifestyle changes. However, it is not understood which factors influence use of an ECA and their health effects.

Objective: We aim to (1) identify whether ECAs can persuade community-dwelling older adults to change their dietary behavior and whether ECA use can decrease loneliness, (2) test these pathways to effects, and (3) understand the use of an ECA.

Methods A randomized controlled trial was conducted. The intervention group received access to the PACO service for eight weeks. The waitlist group received PACO after waiting for four weeks. The primary outcomes, eating behavior and loneliness, were assessed via online questionnaires at intake, waitlist, after four weeks, and after eight weeks. In addition, the primary outcome—use—was assessed via data logs. Secondary outcomes were measured at the same times, via questionnaires or an optional interview

Results: In total, 32 participants completed the intervention. We found a significant correlation between use in minutes on the one hand, and perceived usefulness ($r = .39$, $p = .030$) and enjoyment on the other ($r = .38$, $p = .032$). However, these did not predict use in the full regression model ($F(2,29) = 1.98$, $p = .16$, $R2 = .12$). Additionally, PACO use did not lead to improvements in eating behavior ($\chi^{2(2)} = .34$, $= .85$) or a decrease in loneliness ($\chi^{2(2)} = .02$, $= .99$).

Conclusion: Our study did not provide any concluding evidence about factors that are linked to the use or health effects of ECAs. Future service design could benefit from either creating a functional design catered towards the predominant stage of the targeted population, or by personalizing the service based on an intake in which the end-user's stage is determined.

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Introduction

Embodied conversational agents (ECAs) have been proposed as a promising interaction modality for the delivery of programs focused on promoting lifestyle changes [1], such as physical activity [2–4], nutrition [5, 6] and preconception care [7, 8]. ECAs often have a human-like appearance and communicate via prewritten dialogues. They also have the ability to establish and maintain an empathic relationship, which may make them more engaging then traditional eHealth interventions [9, 10]. Results are promising as ECA interventions are found to be easier to use [5], and are used more frequently [5, 10–12], compared to interventions without an ECA. Nonetheless, ECA use does decline over time, limiting long-term health effects [1, 13–16]. Moreover, it is unknown which factors influence use of an ECA. When designing an ECA, designers are advised to select the right role for the ECA, combine the most important personality characteristics, and use informational, non-judgmental language [17]. In addition, a scoping review identified which use-related factors were assessed when evaluating ECAs for healthy lifestyles. These included usability and user satisfaction, further specified via concepts such as liking, trust and the desire to continue using the ECA. However, evidence for the effects of these concepts on use is limited [1]. Furthermore, evidence of ECAs' health effects and the pathways to effects is scarce and remains inconclusive [1].

In order to assess the pathways to effects and understand ECA use when evaluating an ECA, conceptual models can be used (see Figure 1, and for more details the research protocol of this study [15]). The conceptual model explaining ECA use is based on existing human-computer interaction literature, including the Technology Acceptance Model (TAM)[18]. The key variables in TAM are perceived usefulness and perceived ease of use. Systematic reviews have shown that these two variables typically explain about 40 percent of an individual's intention to use a technology in a variety of contexts [19–21]. However, there is mixed evidence regarding whether or not intention predicts actual use [22, 23]. Since actual use, rather than intention to use, is deemed necessary to achieve any health benefits, use is at the center of the conceptual model. Increased used is expected to improve the intensity of the relationship with the ECA because of its capacity to establish and maintain an empathic relationship, ECA. Usability and perceived usefulness are hypothesized to act as antecedents for use, whereby increased usability is expected to result in increased perceived usefulness. The conceptual model explaining health effects occurring after the use of an ECA, starts with the behavior change techniques, which are expected to lead to an improvement in the three basic psychological needs, autonomy, competence and relatedness [24], and ultimately, through improved health behaviors, in better quality of life. This model is primarily based on the Self-Determination Theory [24] and has an explorative character, whereby the classification from Teixeira et al. was used to form hypothesis for which techniques improve which needs [25, 26]. Hence, the objective of the study is to (1) identify whether ECAs can persuade community-dwelling older adults to change their dietary behavior and decrease their loneliness, (2) assess the pathways to effects, and (3) understand ECA use.

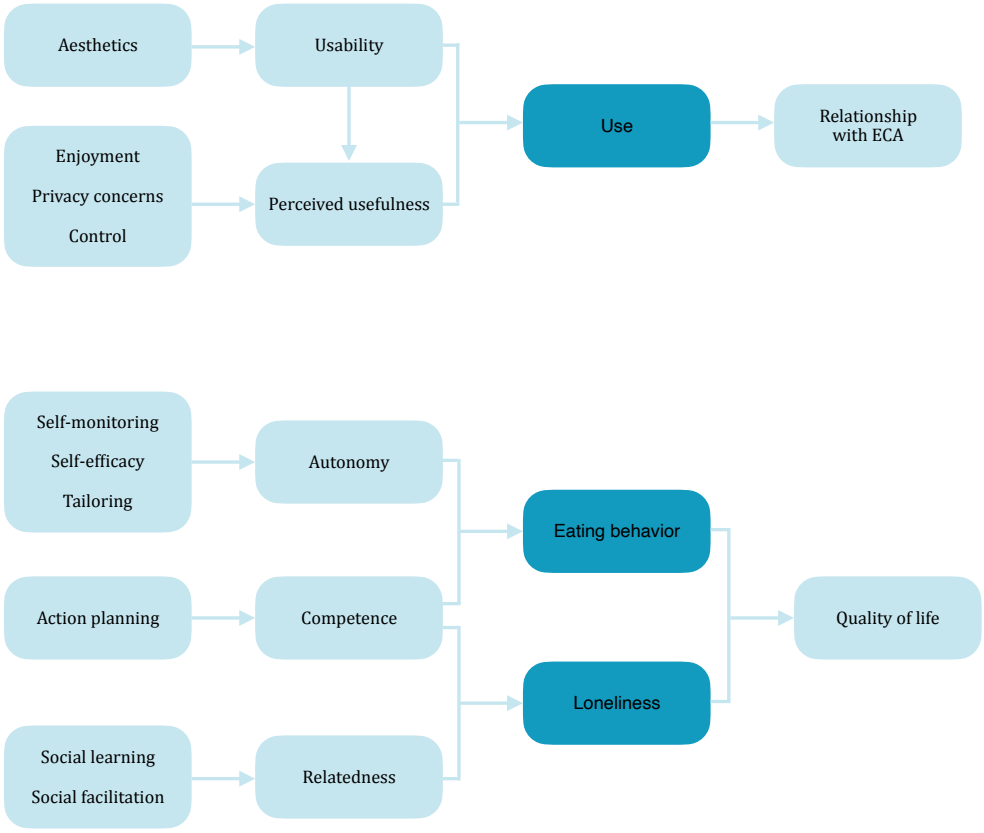

Figure 1: Conceptual model explaining ECA use and Conceptual model explaining health effects.

Methods

Study design

A randomized controlled trial was carried out. Participants in the first cohort received access to the 8-week PACO service immediately, participants in the second cohort served as a control condition as they received access after a 4-week waiting-list condition. The study was pre-registered at ClinicalTrials.gov (NCT04510883) and approved by the medical ethical committee of Wageningen University (number NL73121.081.20). We refer to the study protocol article for all details on the protocol, the development process of the PACO application, and the conceptual models [15].

Participants and procedure

We aimed to include a total of 60 participants, with a 1:1 ratio per cohort. Participants were eligible if they were aged 65 years or older, not in paid employment, and lived alone

and independently at home. In addition, participants needed to speak Dutch, be able to use a tablet or computer by themselves and have a wireless internet connection. The project members recruited participants via research panels, flyers, newspapers, and social media. After providing informed consent, participants were invited to complete the intake questionnaire. They were asked to report their demographics (gender, age, educational level, health conditions, risk of malnutrition [27], and eHealth literacy [28]), whether they owned a device to use for the study, and their motivation to participate. All participants were asked to complete the baseline questionnaire (T0) after creating an account, and another questionnaire after 4 (T1) and 8 (T2) weeks of use. Participants in cohort 2 were asked to complete the additional waitlist questionnaire (Tw) four weeks before T0. In the last questionnaire participants were asked whether they were open to an interview by phone.

Intervention

PACO is a web-based eHealth service in which 2 ECAs engage in dialogue with older adults to motivate them to improve their eating behavior and decrease their loneliness. The service consists of 5 modules, each one applying different behavior change techniques (see Figure 2). The user can engage in dialogue with Herman (the cook, who provides nutritional advice) and Ellen (the peer, who provides social advice). During the onboarding process, the ECAs introduce themselves and explain the PACO program.

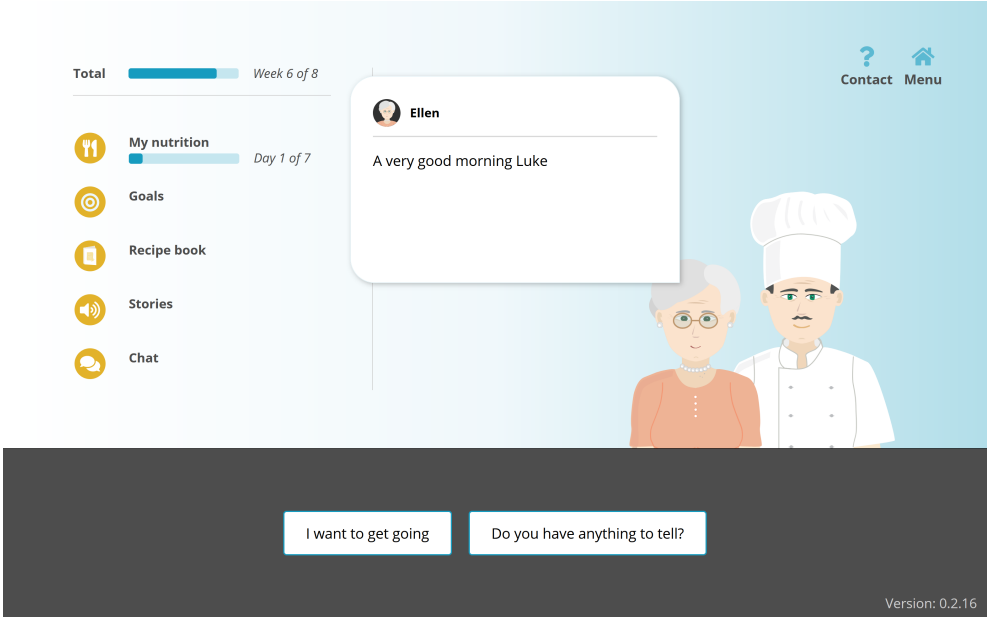

Figure 2: The PACO application.

Outcomes

The primary outcomes include use, eating behavior, and loneliness. Use was assessed via log data, collected on the PACO back-end. Eating behavior was self-assessed by 3 open questions about yesterday's fruit, vegetable and liquid intake, and loneliness via a validated questionnaire (see Table 1 for further details). Willingness to pay for PACO and their experience were measured via self-compiled scales. All other outcomes were measured via validated online questionnaires. Via an interview of approximately 30 minutes, participants were asked further about their experiences with PACO and any behavior changes.

Table 1: Study outcomes measured via questionnaires, per study phase.

Outcome	Scale	Tw	T0	T1	T2
Use-related outcomes					
Relationship with ECA	Rapport Scale [29–31]		-	-	-
Usability	System Usability Scale [32]				-
Enjoyment	Affect Scale [33]				-
Aesthetics	Classic Aesthetics [34]				-
Privacy concerns	Concerns for Privacy Scle [35]				-
Control	Active Control [36]				-
Perceived usefulness	Perceived Usefulness Scale [18, 37]				-
Health-related outcomes					
Eating behavior		-	-	-	-
Loneliness	De Jong Gierveld Loneliness Scale [38]	-	-	-	-
Quality of life	Brief Older People's Quality of Life [39]	-	-	-	-
Autonomy, competence, and relatedness	Basic Psychological Need Satisfaction and Frustration Scales [40–42]	-	-	-	-
Other outcomes					
User experience				-	
Willingness to pay					-

Data analyses

We created single scores for all scales and checked the test assumptions. Due to violation of the linearity assumption, we deviated from the original protocol by using non-parametric tests. The relationship between demographics and the main study outcomes was calculated using Spearman's rho and Mann-U (for gender). Differences between Tw and T0, and in health-related outcomes over time were compared using the Friedman test. Differences in the strength of the relationship with the ECA over time were compared using repeated measures ANOVA. Spearman's rho was used to calculate the correlations between use- and health-related outcomes. Linear regression analysis was used to calculate the multivariate relationships between use, eating behavior, loneliness, and the significant outcomes. Statistical significance level was $p < .05$. Recordings of the interviews were transcribed and thematically analyzed by LK and BM. The data underlying this article will be made available at DANS EASY repository [43].

Results

Drop-out, baseline characteristics and motivation

In total, 51 participants met the inclusion criteria. Nineteen participants did not use the PACO service for 14 consecutive days and were treated as dropouts. Reasons were non-response to e-mails and telephone calls (7), illness (3), lack of time (3) and motivation (2), difficulties with the service (2), or internet issues (1). Eight dropouts had created an account, of which 4 had completed T0. The mean age of the 32 participants was 73.00 years (SD = 5.33); 56.25% were women. In total, 37.50% had completed high school or some associate degree, 59.40% had completed college or university. The mean eHealth literacy score was 29.25 (SD = 4.36), the risk of malnutrition was 9.69 (SD = 1.35). None of the demographics had a significant relationship with use, eating behavior or loneliness, and there were no significant differences for the health-related outcomes between Tw and T0. During intake, participants stated that they were mainly motivated to participate because they were interested in research and in new developments and thought it was important to contribute. Some participated because they were interested in nutrition and wanted to stay healthy or improve their habits.

Health effects

The ECAs were not able to persuade users to change their eating behavior ($\chi^{2(2)} =$ .34, = .85) or decrease loneliness ($\chi^{2(2)} =$ .02, = .99). There were also no significant differences over time in quality of life ($\chi^{2(2)} =$ 2.99, = .22), autonomy ($\chi^{2(2)} =$ .34, = .85), competence ($\chi^{2(2)} =$ 2.32, = .31) or relatedness ($\chi^{2(2)} =$ 2.46, = .29). See Table 2 for all descriptive health outcomes. During the interviews, most participants indicated that they were already eating healthily. Nonetheless, a majority mentioned that the food diary helped them to become aware of their food intake. Some people were even shocked by their observations and described PACO as a wake-up call. About half of the participants also mentioned that they did introduce changes into their diet, such as cooking with more fresh ingredients, baking bread, eating more fruit and vegetables, and eating less meat. With respect to loneliness, most participants mentioned that they already had ample social contacts, even though some stated that they were feeling rather lonely. Apart from the 'bad timing' of the pandemic, four participants mentioned changing things in their social network because of PACO. One participant created for example a list of everyone he knew and contacted them occasionally. Also, the chat connected a few people with each other, and resulted in one-on-one contacts.

The pathways to effects

Following our conceptual model for health, we expected to find a significant correlation between minutes spent on the different modules and eating behavior. However, this was not the case ($p > .05$, see Table 3 for all correlations). With respect to the other pathways, we found that competence did correlate with eating behavior (r = -.38, p = .03), and also

predicted eating behavior over time ($F(1, 30) = 4.30$, $p = .047$, $R2 = .13$). Quality of life ($r = -.60$, $p < .000$), autonomy ($r = -.38$, $p = .03$), relatedness ($r = -.59$, $p < .01$) and number of chat messages ($r = .72$, $p = .03$) did correlate with, but did not predict ($F(4, 8) = 1.32$, $p = .40$, $R2 = .14$), loneliness.

Table 2: Descriptive health outcomes (M ± SD).

	Scale	Tw	T0	T1	T2
Eating behavior	0 - 300	237.04 ± 45.33	215.84 ± 72.12	215.70 ± 65.92	223.01 ± 71.28
Loneliness	1 - 5	2.27 ± 1.71	2.47 ± 1.78	2.62 ± 1.91	2.44 ± 1.92
Quality of life	13 - 65	54.93 ± 4.93	56.09 ± 5.60	55.47 ± 6.56	54.78 ± 5.85
Autonomy	1 - 5	4.11 ± .42	3.99 ± .54	4.05 ± .60	4.07 ± .56
Competence	1 - 5	4.24 ± .37	4.05 ± .58	4.19 ± .52	4.22 ± .57
Relatedness	1 - 5	4.21 ± .38	4.33 ± .56	4.31 ± .53	4.34 ± .51

Understanding ECA use

Use of PACO and trends over time

On average, participants logged-in 39.97 times ($SD = 37.38$, range = 10 – 197). Minutes per week decreased from a median of 69.66 in week 1, to 21.57 minutes in week 8 (see Figure 3). Results of the Friedman test confirm this decline over time, by showing a significant difference in use between weeks ($\chi^{2(7)} = 31.46$, $p < .00$). The median time for using PACO was at 15:15:05 (hh:mm:ss). The average total time spent on PACO was 6:30:00 hours ($SD = 05:54:01$), and 11:10 minutes ($SD = 05:44$) per session. The average number of modules per session was 2.39 ($SD = 0.34$). Most time was spent on the food diary (85.45%), followed by recipes (6.36%), goals (4.58%) and the stories (3.61%). In total, 11 participants signed-up for the chat. They sent a mean of 27.78 messages ($SD = 15.55$, range = 13 – 67). During the last interaction, the last module was most often the food diary (41.67%), followed by the chat (25.00%), goals (16.67%), recipes (12.50%) and stories (4.17%).

Use-related outcomes

Usability, aesthetics, privacy concerns and perceived control were rated above the scale midpoint (see Table 5). The enjoyment and usefulness of PACO were rated below the scale midpoint, and perceived usefulness was rated rather low. In total, 93.8% indicated they were not willing to pay for PACO. With respect to the amount, and contradictory, 87.5% would be willing to pay €0, 12.5% would be willing to pay €5. Following our conceptual model for ECA use, we found that aesthetics correlated significantly with usability ($r = .44$, $p = .01$), and enjoyment with perceived usefulness ($r = .48$, $p = .005$). Although we found that perceived usefulness ($r = .39$, $p = .030$) and enjoyment ($r = .38$, $p = .032$) correlated with use in minutes (see Table 4 for all correlations), in the full regression

Table 3: Spearman correlations for health-related outcomes and PACO modules.

	1	2	3	4	5	6	7	8	9	10	11
1. Eating behavior	-										
2. Loneliness	.10	-									
3. Quality of life	-.21	-.60**	-								
4. Autonomy	-.11	-.38*	.75**	-							
5. Competence	-.38*	-.16	.47**	.55**	-						
6. Relatedness	-.01	-.59**	.67**	.60**	.43*	-					
7. Food diary	.19	.01	.13	.09	.06	.12	-				
8. Goals	.12	-.09	.20	-.02	-.32	.13	.02	-			
9. Recipes	-.27	-.23	.14	-.03	-.24	.20	-.14	.34	-		
10. Stories	.04	-.13.	36*	.16	-.01	.24	-.13	.44*	.11	-	
11. Chat	.01	.72*	-.45	-.31	.06	-.29	-.27	-.37	-.21	.03	-

Note: **p $<$ .01; * p $<$ .05

Table 4: Spearman correlations for use and use-related outcomes.

	1	2	3	4	5	6	7	8
1. Use	-							
2. Relationship with ECA	-.13	-						
3. Usability	-.05	-.01	-					
4. Perceived usefulness	.39*	.31	-.13	-				
5. Aesthetics	.34	.28	.44*	.27	-			
6. Enjoyment	.38*	.28	.23	.48**	.78**	-		
7. Privacy concerns	.30	.01	.35	.09	.54**	.32	-	
8. Control	-.01	.32	.48**	.01	.51**	.38*	.48*	-

Note: **p $<$ .01; * p $<$ .05

model, these did not predict use ($F(2,29) = 1.98$, $p = .16$, $R2 = .12$). During the interviews, participants stated that they did read the module content, but did not truly engage, often reporting that the content was not helpful. For example, participants listened to stories and read recipes, but did not act. In some cases, this was due to issues of tone, such as storytellers being seen as patronizing or the discomfort of endorsing dining alone. In other cases, such as the chat, participants simply did not wish to speak to people they did not know, or, if they did so, the conversations felt shallow.

Table 5: Descriptive use outcomes.

	Scale	Outcome (M ± SD)
Usability	0 – 100	64.53 ± 17.98
Enjoyment	1 – 7	3.26 ± .81
Aesthetics	1 – 7	4.82 ± 1.21
Privacy concerns	1 – 7	5.14 + 1.28
Control	1 – 7	4.78 ± 1.20
Perceived usefulness	1 – 7	2.56 ± .99

Relationship with the ECAs

The strength of the relationship with the ECAs decreased over time ($F(1.72,53.33) = 4.22$, $p = .02$, also see Figure 3). Post-hoc analyses with Bonferroni correction showed that this difference is significant between T1 and T2 ($p = .047$). Contrary to our expectation, the relationship did not correlate with use ($r = -.13$, $p = .47$). During the interviews, most participants were neutral about the ECAs, or told not having noticed them. Six participants mentioned that the ECAs made PACO easier to use, more engaging or more enjoyable compared to plain text, or even described them as 'fantastic'. On the other hand, three participants found the ECAs to be childish, unreal, and found themselves too rational to see that the ECAs are not actual persons.

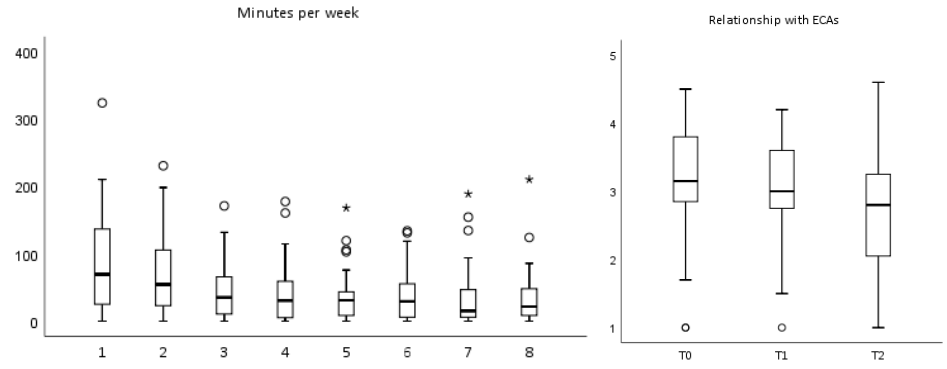

Figure 3: Minutes per week and relationship with the ECAs over time.

Discussion

In this study we were interested in the effectiveness, the pathways to effect, and the mechanisms that explain the use of an Embodied Conversational Agent (ECA) targeting eating behavior and loneliness among older adults via a randomized controlled trial. Results show that neither the ease of use of the PACO service, nor user experience explain the extent to which PACO was used. Furthermore, the use of PACO did not result in improved eating behavior or loneliness. Our findings might, on first sight, contradict our hypotheses, and add to the mixed evidence base on nutritional ECAs [5, 6, 44]. On the other hand, we can also take these results as valuable lessons for the future design of eHealth services.

Participants did become more aware of their eating behavior due to the self-monitoring tool, and thus of the behaviors they could improve. In terms of the Precaution Adoption Process Model (PAPM) [45], they were 'Deciding about acting'. However, in the interviews, participants expressed high self-perceived health, and no need for change. This suggests users might well have ended up in the stage of 'Decided not to act'. It is known that users' stage plays a significant role in the perceived persuasiveness of the different behavior change techniques [46]. Hence, our participants should have been nurtured in different needs as they still resided in the earlier stages of the model. If this was the case, then future service design could benefit from either creating a functional design catered towards the predominant stage of the targeted population, or by personalizing the service based on an intake in which the end-user's stage is determined.

To our knowledge we are among the first to study factors that help understand ECA use. Surprisingly, we found that the use of PACO could not be explained by its usability, privacy concerns, the perceived usefulness or level of enjoyment. Furthermore, positive ratings on aesthetics and perceived control were not associated with time spent using PACO, but these factors did have a positive correlation with its usability. According to Klaassen et al., low usability of an ECA can influence potential health effects [4]. This might seem contradictory to our results. However, it might also suggest that use will decline if a service is too difficult to use, and that users will not engage more if the usability is sufficient. Which factors do positively influence the use of an ECA is yet to be explored.

This study knows some limitations. First, we received barely any responses on our flyers, social media posts and advertorials. The interview in newspapers and phone calls to members from the research panels resulted in more, yet still limited, responses. Due to the smaller sample size the overall power was low. We consider not measuring the stage of the PAPM a second limitation of this study. We suspect that the stage is a factor that provides more insight into both the use and effect (i.e., participants who use the service more frequently, and report health-related effects, are likely to act). Finally, the ongoing COVID-19 pandemic might have influenced our results. We did rewrite the content of PACO to match the current situation and focused on online alternatives for engaging in social interactions. Nonetheless, participants did feel they were not able to be more socially active due to the governmental restrictions. Loneliness even increased in our target group

during the pandemic [47]. Hence, this might have influenced the absence of decreased feelings of loneliness.

In conclusion, this study illustrates how we can use a conceptual model to guide the evaluation of an ECA service in terms of both use and health effects, although it did not provide us with any concluding evidence for actual effectiveness. Nonetheless, our results provide a valuable direction for following studies in this emerging field.

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Chapter 7

General discussion

There is not, and never will be, one single eHealth tool that is capable of supporting healthy ageing. All individuals have different needs and preferences. Therefore, it is necessary to create a variety of tools, including health monitors, assistive technologies, sensor technology, video games, and wearables. It is essential to understand what works for whom and why. Only then can effective eldercare eHealth services be offered that, combined, support the health and the well-being of people in older age. This dissertation focused on a specific eHealth tool: the Embodied Conversational Agent (ECA). The aim of this study was to provide insight into how to design and evaluate ECAs that support healthy living. In this last chapter, the main conclusions of Chapters 2 to 6 are first shared, followed by critical reflections, suggestions for the future development of eHealth interventions, and practical guidelines.

Main conclusions

Although the first articles on ECAs for coaching people in relation to a healthy lifestyle date back to 2005, the field is still in its infancy (Chapter 2). Only a small number of evaluation studies have appeared, and none of the ECAs developed have been implemented in real life. Regarding the design of ECAs, human-centered and stakeholder-inclusive design approaches are recommended by the eHealth community, but have been underused by ECA developers. Multiple behavioral theories and therapy-derived principles have been implemented in ECA tools. However, reporting on the development process has been poor and conceptual models have not been used to explain and study the health effects of ECAs. Nonetheless, ECAs have made eHealth interventions more engaging. Not surprisingly, evidence on ECAs' effects, in terms of improvements in behavior, knowledge, and motivation, have remained inconclusive.

In the PACO research project, taking a human-centered design approach, the focus was on persuading community-dwelling older adults to transition to dietary behavior change (Chapter 3). First, the meaning of healthy eating was discussed, as also the preferred approaches to overcome barriers towards healthier eating. The first main finding was that older adults approach eating from a holistic perspective. This meant that older adults evaluated eating not only in terms of nutrients, ingredients, or components, but also in terms of eating mindfully and in a well-balanced way. Action planning and self-monitoring were older adults' preferred approaches, which should aim to increase perceived competence levels, support autonomy, and address feelings of loneliness. Next, the design requirements for the ECA were discussed. There were five preferred personality characteristics: friendly, warm, trustworthy, concerned, and competent. The communication style should contain some humor and non-judgmental language.

Matching the appearance of an ECA with the health topic at hand increased the ECA's persuasiveness and intention to use (Chapter 4). A female peer was, for example, preferred for offering advice on combating loneliness, and a cook for offering healthy recipes. There was no effect on preference of older adults' gender or age in the online experiment. With respect to the tone of voice, the following requirements were preferred by a majority of

older adults: use of short sentences, including small talk, allowing users to talk about their own life, asking users how they wanted to be called, using a formal tone, and adjusting greetings to the time of day.

When an ECA is being evaluated, it is important to focus on both use and health effects (Chapter 5). In order to understand ECA use and the pathways to effects, two conceptual models were developed – one for use and one for health effects. The conceptual model explaining ECA use has usability and perceived usefulness as the main predictors for use, which is expected to lead to an improved relationship with the ECA. Good aesthetics are further expected to lead to improved usability. Enjoyment, privacy concerns, and perceived control are expected to increase perceived usefulness. The conceptual model explaining health effects includes behavior change techniques (BCTs) as predictors for the three basis psychological needs (autonomy, competence, and relatedness). An improvement in these needs is expected to lead to improved eating behavior and decreased feelings of loneliness, thereby leading to an overall improvement in quality of life. In order to gain a fine-grained understanding, it is recommended to combine questionnaires, interviews, and logdata collection. Logdata should be used to determine the frequency of login, time spent on each module, time spent in total, time of use, and time of dropout.

Contrary to the hypotheses presented in Chapter 5, neither ease of use nor perceived usefulness explained the extent to which PACO was used (Chapter 6). Positive ratings on aesthetics and perceived control showed a positive correlation with usability but were not associated with time spent using PACO. Users became more aware of their eating behavior, but the use of PACO did not result in improved fruit and vegetable intake, or decreased feelings of loneliness.

Critical reflections

During the PACO development process, the best practices of eHealth development, as guided by the CeHRes Roadmap [1], and the best practices from different fields were adopted. Among other things, end-users and other stakeholders were involved, various theories and BCTs were incorporated, and conceptual models were created. However, PACO did not result in significant improvements in health behavior, nor was it able to predict use. As in every project, there were time constraints and limited resources available, mainly regarding software development. In this section, four points are introduced to critically reflect on the work presented in this thesis: the participatory-development process and the available theoretical evidence, the potential of personalized nutritional advice, the use of ECAs to combat loneliness, and the added value of ECAs.

Questioning our methodology

The first point addresses something that should have been done differently during the participatory development process. In the literature on the development of eHealth, the involvement of end-users is deemed essential [2], because it is required for the successful

development of eHealth services [1]. Hence, during the co-creation sessions (Chapter 3), older adults' needs and wishes were elicited with respect to healthy eating, healthy living, and their preferences for an ECA. Combined with existing literature and theory, and the results of the stakeholder analysis, these findings were translated into concrete modules for the PACO service. The process continued by focusing on appearance, tone of voice, and usability. However, the translation of users' needs and wishes into eHealth functionality was not verified, and there was no focus on the acceptance of PACO in the early phases of development. An indication that this should have occurred is the low score on perceived usefulness as found during the evaluation (Chapter 6). Perceived usefulness is important for acceptance, as it is assumed that an eHealth intervention will not be used if it is not perceived as useful [3]. The eHealth End-user Walkthrough introduced by van Velsen et al. [4] is an evidence-based method for testing the acceptance of an eHealth innovation, but it is in the early stages of development. During a walkthrough, a participant is guided by using the technology via a scenario, a persona, and a low-fidelity prototype. During and after the demonstration, the participant is questioned about factors that may affect acceptance. This was an important extra step that should have been taken and probably would have improved PACO's acceptance.

The second point is more theoretical and relates to a lack of evidence on which BCTs to use. It is known that eHealth interventions that incorporate more BCTs, and make more extensive use of theory, are associated with larger effect sizes compared to interventions that incorporate fewer techniques and make less extensive use of theory [5]. In Chapter 2, it was shown that, although most ECA interventions were based on one or multiple theories and therapy-derived principles, the selection of theory and BCTs remained unmentioned in articles and the selection was not supported by evidence. The decision to select Self-Determination Theory (SDT) was based on the co-creation sessions. However, it was striking that there was a limited amount of literature available on the BCTs that are capable of supporting the three basic psychological needs. There was some relevant literature [6], and the project team already included experts from different fields to match the BCTs to the needs. Nevertheless, it seems that the evidence base on translating theory via BCTs in an eHealth intervention is limited. Hence, one of the aims of the evaluation in this study was to verify this in the conceptual model explaining health effects (Chapter 5). Unfortunately, it was not possible to add conclusive evidence on whether the BCTs – self-monitoring, self-efficacy, tailoring, action planning, social learning, and social facilitation – can improve feelings of autonomy, competence, and relatedness. Nonetheless, it remains important to use a conceptual model for the development and evaluation of eHealth interventions in order to further develop the understanding of interventions' working mechanisms.

The last point concerns the actual methodology, specifically the small sample size, starting with the co-creation study (Chapter 3). Coordinators of the community plus buses of the National Foundation for the Elderly (NFE), which are existing communities of people who conduct activities together, were contacted and asked whether they were willing to recruit participants. It was expected that a majority would be willing to support in the

recruitment, but this was not the case. They often did not respond to the researchers' requests, making it difficult to explain their reasons for non-response. This resulted in a total sample size of 13 participants for the co-creation study. Given that the PACO content was based mainly on the needs and wishes defined in this study, a larger sample size would possibly have enhanced the chances of improving PACO's usefulness. The same point applies to Chapter 5. The aim was to include a total of 60 participants to complete the intervention, in order to verify the conceptual models, already accounting for the standard high rate of drop-outs in eHealth research [3]. However, it was difficult to recruit participants, and the total sample size was too low to complete the necessary statistical tests for verifying the conceptual models. Again, it is difficult to pinpoint why exactly people did not want to participate, as people did not respond to our variety of recruitment strategies. The literature on the use of eHealth tools for health promotion and primary prevention among older adults mentions various barriers. These include, for example, a lack of time to participate, motivation, or eHealth literacy. Other barriers relate to unclear information on the device or a lack of guidance [7]. Indeed, 19 of the 51 participants dropped out, and their reasons included lack of time and motivation, and difficulties with the service. However, not all reasons could be ascertained, as most participants that stopped using PACO could not be reached via e-mails or telephone calls. Hence, apart from a lack of time and motivation, it is hard to state how attrition rates can be improved in future research.

Personalized nutritional advice

A major question that arose with during the development of PACO relates to the origin of the nutritional advice. More specifically, should ECAs provide nutritional advice based on users' self-reported nutritional intake – for example, about their insufficient protein intake or Vitamin D deficiency, similar to the app My FitnessPal? Or should ECAs help users only to self-report their intake and not provide any advice? In order to determine which strategy was most appropriate for PACO, it was decided to involve the preferences of end-users. For the usability study [8], a mock-up was created without an ECA providing feedback and explicitly asked participants whether they would like to receive personalized feedback on their consumption of macro- and micro-nutrients. The results were mixed; about half of the participants would like to receive feedback, whereas the other half saw no need.

An important limitation of providing personalized nutritional advice based on users' nutritional intake relates to the reliability of self-reporting nutritional intake. It is well known that recall formats are prone to measurement errors [9, 10]. Users miscalculate, for example, their portion sizes, do not differentiate between a raw and a cooked product, or forget the salt added to their potatoes. This means that the ECA's advice is incorrect, and this can cause serious problems, especially in the target group of older adults, who often suffer from one or multiple chronic diseases and might need specific diets [11]. Furthermore, this strategy is also more time-consuming for the software developer to implement in an eHealth service. A limitation of assisting users only in self-reporting is

that users have different health literacy levels [12] and are not equally able to translate their food diary into nutritional advice for themselves. Hence, they are less likely to change their behavior.

Combined with the greater technological challenge, it was decided not to provide personalized nutritional advice based on users' nutritional intake, but instead to have people set their own goals and use the food diary as a probe to increase awareness of their intake and provide general nutritional information. However, this approach is not ideal. The development of eNutrition is a promising solution to this problem. eNutrition refers to ''the use of ICT to develop and support personalized healthy nutrition''. Boland and Bronlund argue that eNutrition is the next dimension in eHealth [13]. They foresee that food intake can be automatically monitored in two ways. The first way focuses on using recipes, changes in the food inventory at home, and food purchases and disposals as a method to automatically monitor food intake. The second way focuses on a range of direct measurements, such as food image capturing and analysis and the use of various on-body sensing systems to monitor eating behaviors. Hence, the combination of reliable and automatic monitoring of food intake on the one hand, and personalized nutritional advice from an ECA on the other hand, might be a persuasive strategy to help older adults improve their nutritional intake.

Combating loneliness

Are ECAs able to help older adults feel less lonely? In PACO, the ECA was employed mainly as a coach who persuaded users to undertake more social activities, such as volunteering or knitting groups, and facilitated a WhatsApp group. In addition, users could set goals for social interaction and receive reminders. However, no improvement was found in feelings of loneliness among the participants (Chapter 6). According to a recent scoping review by Gasteiger et al., robots can help to combat loneliness among older adults [14]. The most reported strategy is the offering of social companionship. Thus, these robots aim to diminish feelings of loneliness directly. The authors also looked at ECAs and conclude that ECAs use the same technique; however, there is as yet insufficient research available on ECAs' effects on loneliness [14].

It would be worthwhile to continue developing ECAs that offer social support and study their effects, including the working mechanisms, on loneliness. Therefore, it is necessary to study how to integrate the ECA in users' everyday life in such a way that support is offered at the right moment and in a context when a person needs it most and is most likely to be receptive. Such an intervention design, referred to as a Just In Time Adaptive Intervention (JITAI), "adapts the provision of support (e.g., the type, timing, intensity) over time to an individual's changing status and contexts" [15]. JITAIs hold enormous potential for promoting health behavior change [16]. In the case of social support, an ECA might suggest, for example, joining a social event nearby when a user has not been out for a couple of days. Most ECAs were used on a mobile phone, tablet, or computer [17]; however, there are many other technologies available, such as robots, home speakers, and

wearables. Hence, an ECA could become a traveling companion that adapts to the devices that are available and nearby – for example, the home speaker could suggest joining an event or offer a chat.

If the technology existed, it would also be important to study the soft impact of technology on users. Imagine, for example, Mrs. Smit from the introduction, who has an ECA as her only companion, but does not feel lonely. Is this something that should be encouraged or avoided? On the one hand, it can be stated that, if she is happy with the ECA, it is up to her to decide. Maybe it will even spill over into real-life relationships. On the other hand, what if it adds to a diminished capacity to form real relationships? There are ample articles that debate the ethical implications of embodied artificial intelligence (AI), especially for mental health. A thematic literature search lists various ethical issues and concerns of embodied AI that are raised in psychiatry, psychology, and psychotherapy. These include, for example, the lack of guidance on the development of AI applications, the clinical integration and training of health professionals, and gaps in ethical and regulatory frameworks [18]. New research on ECAs in the context of social support should study these ethical issues and concerns in order to develop an ECA that can be implemented in practice.

The added value of ECAs

To conclude, one last question remains: what is truly the added value of ECAs to eHealth? In the scoping review (Chapter 2), it was concluded that ECAs make an eHealth intervention more engaging than traditional eHealth interventions. In their systematic literature review, Perski et al. conceptualize engagement as "the extent (e.g. amount, frequency, duration, depth) of usage and a subjective experience characterized by attention, interest and affect" [19]. However, it is unknown why ECAs make an eHealth intervention more engaging. This is problematic, as it prohibits researchers from using these mechanisms to further improve ECAs' engagement and to improve engagement in other eHealth services. Three different explanations for why an ECA is more engaging are proposed in this thesis.

A first potential explanation was offered back in 2004, when one of the first books on ECAs was published: From Brows to Trust, by Ruttkay and Pelachaud. Although the context was not limited to a specific context, the authors provide a valuable overview of the state of affairs at that time. They state that ECAs are "meant to make a computer more easy to use" [20]. This was a valid argument back then, at a time when 64% of older adults had never used the internet at all [21]. Nowadays however, internet use is almost a necessary skill. Indeed, the evaluation study in Chapter 6 illustrated that eHealth literacy was rather high and that there was no correlation between eHealth literacy and the use of the PACO service. Thus, if it is not its usability that makes an ECA more engaging than a traditional eHealth intervention, what is?

In the literature, the capacity to establish and maintain an empathetic relationship is a common argument for the use of ECAs in eHealth interventions [22–24]. However, as shown in Chapter 6, this is not necessarily true for all ECAs. It was shown that the

strength of the relationship with the ECA weakened over time and did not correlate with use. Furthermore, the strength of the relationship was not measured at all in the reviewed evaluation studies in Chapter 2. In the literature review on design features [25], it was observed that ECAs with relationship-building capacities were liked better and scored higher on usability. These capacities include, for example, understanding users' feelings and offering empathy. However, there was no effect of these capacities on users' health outcomes. This questions whether a relationship with an ECA can be established and whether it adds to an ECA's effectiveness. Moreover, this indicates that it is not the relationship with an ECA that explains why an ECA is engaging.

A last factor that might explain why an ECA is more engaging is the novelty of ECAs for the general population. Chatbots, for instance, are becoming more common, mainly in customer service [26]. In the Netherlands for example, there is Billie from Bol.com, the digital assistant from Eneco or NS. However, ECAs are not so common. Of all the PACO project participants, only those who had previously participated in ECA research indicated that they had interacted with an ECA before. Furthermore, two reviews on ECAs in the healthcare setting show that they have not yet been implemented [17, 27]. To conclude, the added value of ECAs to eHealth lies in improved engagement, which can perhaps be explained by the novelty effect, although this is an explanation that has yet to be tested in ECA research. An important downside is the well-known novelty effect. In human–computer interaction research, the novelty effect is defined as a person's subjective "first responses to using a technology, not the pattern of usage that will persist over time as the product ceases to be new, to him or her" [28–30]. Prior studies have noted that, as the novelty effect wears off, many users discontinue use of new technologies, such as domestic robots or text message reminders [30–32]. This leads to consideration of the future development of eHealth.

Future development of eHealth

To take the field of eHealth development to a higher level, two research directions should be explored. The first direction focuses on people who are already motivated to change their behavior during the development process. The second centers around short-term eHealth interventions.

One might ask whether eHealth technologies should keep trying to motivate a-motivated users. It has been shown in this thesis that participants do not necessarily participate because they want to change their lifestyle. They can be motivated, for example, because they believe it is important to contribute to research. However, outside the research context, it is known that the main users of health apps are people with excellent health and motivation to change their lifestyle [33, 34]. Therefore, it is surprising that, during development and evaluation, eHealth interventions generally do not considers users' levels of motivation [35]. Targeting only motivated users implies that the functional design of an eHealth service needs to be different in such a way that it meets the needs and requirements of this group of users. This applies, among other things, to the persuasive features offered.

Users who are externally regulated, for example, do not appreciate monetary rewards and implementation intentions as persuasive features [36]. An important limitation of targeting only motivated people is that people who would perhaps benefit most from changing their lifestyle behaviors will not be reached. Because unmotivated people are not influenced by persuasive features [36], other interventions, such as motivational interviewing or environmental interventions [37], are needed for them.

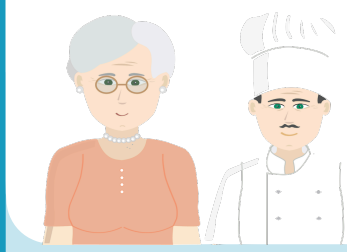
Low and discontinued use is, unfortunately, the standard for many eHealth interventions [38]. Based on the assumption "the more use, the better", most of the interventions aim to engage users as much as possible, even though justifications for intended use are often missing [39]. Many articles and models have appeared on adherence, engagement, and related concepts (see for example [19, 39–41]) – to such an extent that Perski even spoke about "the engagement crisis" [42]. Hence, one might wonder whether it is possible to engage most of the users for a longer period when an eHealth service aiming for health behavior change is the objective. Therefore, the potential of short-term interventions is an important study direction. To provide an example, psychological brief interventions are very promising [43, 44] and might offer a new type of eHealth intervention: one of high frequency and short term. Another example is the use of eHealth interventions aimed merely at closing the intention–behavior gap, instead of actual behavior change. Thus, instead of trying to solve the engagement crisis, and looking at engagement in the same way as in past decades, maybe it should be redefined.

Practical guidelines

All the empirical findings in this study were translated into an overview of practical design guidelines for ECA eHealth interventions. However, the focus of the PACO project was only to a certain degree on the appearance of ECAs. Therefore, this study contributed to a literature review on design features [25] and to ter Stal et al.'s [45] overview of state-of-the-art design strategies for appearance. These findings were also used to develop the guidelines. The guidelines are meant to help people from the creative industry to design their own health ECA and consist of four categories: co-creation, appearance, content, and tone of voice. All the guidelines are presented hereunder. These guidelines, which form the basis of the PACO service, are already being implemented in the ECA service of the European Horizon 2020 project 'PHArA-ON'. Two project partners (Roessingh Research and Development and the NFE are involved in this project and link PACO to the community plus buses of the NFE (which were used for recruiting participants in Chapter 3).

Creating Embodied Conversational Agents

Embodied Conversational Agents (ECAs) can be a valuable tool to persuade people into changing their lifestyle. Imagine an ECA that helps older adults changing their eating behavior, by engaging them in dialogue with a peer or professional. But what are the key elements for creating a successful ECA?



"Co-creation is a creative process in which users, researchers and designers actively collaborate and jointly explore the needs and goals of the end-users and the technology"

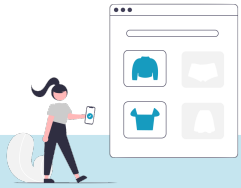
In a 3-year project (PACO), in which partners from academia (Wageningen University & Research), the creative industry (WAAG), eHealth development (Roessingh Research and Development) and social services (the National Foundation for the Elderly) work together, we uncovered the best practices for ECA creation. With our different expertises we setup various studies, including a literature review, a stakeholder analysis, focus groups, co-creation sessions, an online experiment, a usability study, a pilot evaluation, and an evaluation.

In this document we provide an overview of the most important, evidence-based and practical guidelines for the creation of ECAs in the field of health behavior change. These guidelines are specifically written for the creative industry, but can be relevant for anyone who wants to create ECAs.

Co-creation

An eHealth tool is used more often, and generates better health outcomes, if the tool is co-created. End-users can be involved in the design process via a number of ways.

- Ask end-users about their views on the health problem, and their needs and wishes for the technology
- Ask end-users to conduct specific tasks with a prototype (e.g. create an account) to improve the usability
- The most important UX aspects are 'usefulness' and 'enjoyability'; test whether the ECA is perceived as such
- Treat the end-users as the experts during an interview / focus-group, and create a warm climate (e.g. a nice location, transport, lunch)



Appearance

Appearance and first impressions do matter for future interactions. Already within the first seconds people have an opinion about other humans, and the same applies to ECAs.

- Match ECAs' and users' gender, age and culture (e.g. adapting the skin colour, choice of words and directness to that of the user)
- The more advanced its functionalities, the more human-like its appearance should be
- Convey an ECA's expertise using its clothing and body shape
- Implement emotion via ECAs' non-verbal expressions

Content

The content aims to support behavior change, by integrating behavior change techniques into the dialogues. These components need to be relevant to the behavior, while the behavioral focus needs to be clear. We focussed on healthy eating.

- Take a holistic perspective towards healthy eating (e.g. also focus on mindful eating, well-balanced, or eating together with others)
- Self-monitoring and action planning are powerful tools to support healthy eating
- Tailor the components towards users' readiness to change their behavior

Tone of voice

Apart from what an ECA says, it is important things are said. This determines to an important degree whether users adopt ECAs' advice.

- Implement emphatic behavior (e.g. say "I understand that it is not always easy to reach your goal on a working day")
- Implement the following personality traits: friendliness, warmth, trustworthiness, concern, competence
- Include humor in the dialogues, but not too much

Mrs. Smit

In conclusion, imagine it is the year 2030 and Mrs. Smit from the introduction is 93 years old. She is taking a walk in the park when she receives a message on her Apple Watch 8 from her ECA named Ellen. Ellen has noticed that a close friend of Mrs. Smit is taking a walk in the same park and asks whether she would like to meet her. Mrs. Smit likes this idea and agrees to meet at a spot central to their respective locations. They both receive a visual map and directions to the location on their phone. Coincidentally, this is very close to a nice lunch hot spot. Neither has had lunch yet, so they decide to order a healthy sandwich with tomatoes, followed by some tea and tompouce (mille-feuille), because healthy ageing is 'all about balance'.

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Supplementary materials

Chapter 2

Search string

("animated character*" OR "artificial agent*" OR "artificial intelligence assistant*" OR "assistant chat program*" OR "assistive social agent*" OR "chatbot program*" OR "communicative agent*" OR "companion agent" OR "companion assistant*" OR "conversational agent*" OR "conversational assistant*" OR "digital assistant*" OR "embodied agent*" OR "embodied conversational agent*" OR "interactive agent*" OR "interface agent*" OR "online chat program*" OR "pedagogical agent*" OR "persuasive ECA" OR "relational agent*" OR "relational assistant*" OR "software agent*" OR "virtual agent*" OR "virtual assistant*" OR "virtual character" OR "virtual coach*" OR "virtual counselor*" OR "virtual health counselor*" OR "virtual health agent*" OR "virtual health coach" OR "virtual human" OR "virtual patient advocate*" OR "virtual therapist*" OR "virtual web assistant*" AND "activ*" OR "alcohol" OR "behavio?r change" OR "diet" OR "exercise*" OR "health*" OR "lifestyle" OR "mindful*" OR "nutrition" OR "obese" OR "obesity" OR "overweight" OR "pedestrian" OR "physical activity" OR "sedentar*" OR "sleep" OR "smok*" OR "sport*" OR "walk*" OR "weight loss")

Table S2.1: Options and limits per database.

Database	Field	Options and limits
PsycINFO	Search in	Title or abstract (ECA) and abstract (lifestyle)
	Language	English
	Document type	Journal article
MEDLINE	Search in	Title (ECA) and abstract (lifestyle)
	Language	English
	Document type	Journal article
Scopus	Search in	Title and abstract
	Language	English
	Document type	Article

Table S2.2: Categories, components and definitions used for data charting.

Category and component	Definition
Article information	
Publication information	The APA reference of the article
Country	The country in which the study took place
Aim	What the study aimed to find out
Study information	
Duration	The number of weeks or months the study lasted per study part
Setting	The setting in which the ECA was tested
Recruitment	The recruitment strategy used to recruit participants
Race	The social demographic background of the majority of the participants
Gender	The gender of the participants included in the allocation
Number	The number of participants in the intervention and follow-up, included in the allocation
Age	The age category of the participants: ▪ Preschoolers: 0 - 4 years ▪ Children: 5 - 12 years ▪ Adolescents: 13 - 17 years ▪ Young adults: 18 - 24 years ▪ Adults: 25 - 64 years ▪ Elderly: $>$ 65 years
Study design	Method used to evaluate the intervention
Description ECA	
Term ECA	The term which is used to name an ECA in general
Description ECA	The description which is used to describe an ECA in general
Design and content	
Development process	Information about the development process of the content of the ECA
Development phase	The development phase of the intervention the article describes ▪ Development: The intervention is still subject to changes, and measures are related to usability, satisfaction, and feasibility. Measures do not yet include thorough evaluation based on relevant clinical outcomes. ▪ Piloting: The intervention is near completion, and relevant behavioral outcomes are considered in the evaluation. Usability, satisfaction, and feasibility outcomes can go hand-in-hand with behavioral outcomes. Evidence is not yet significant enough to give enough confidence to apply it in practice. ▪ Evaluation: The evaluation revolves primarily around the intervention's effect on behavioral outcomes. Sample sizes are typically larger, and methodology is more rigorous. These interventions have been evaluated to the extent that their practical application could be considered.

	▪ Implementation: The intervention has already gone through the evaluation phase, and has been used in practice for some time.
Name ECA	The name which is given to the specific ECA
Name intervention	The name which is given to the intervention
Design	Information about the design of the appearance of the ECA
Design process	Information about the design process of the appearance of the ECA
Image	An image of the ECA
Support	
Aim of support	The aim of the intervention: type of lifestyle behavior the agent is targeting
Supported services	Other services used to support the intervention
Behavior change technique	All behavior change techniques used
Theory	Theories or principles used to change behavior
Content	Information about the content the ECA offers
Implementation	
Implementation	Description of the activities undertaken for the implementation of the intervention in practice
Formative evaluation	
Outcome measure	The method used to collect the data: the outcome type measured ▪ Behavior: Whether or not the study assesses user behavior ▪ Knowledge: Whether or not users acquired targeted knowledge by using the intervention ▪ Motivation: When users report on their motivation to change ▪ Usability: Whether or not users have trouble using the intervention ▪ Usage: How often and how the intervention is used ▪ User satisfactions: Whether or not users respond positively to the intervention
Conclusion authors	The main conclusion of the study, as described in the abstract
Conclusion reviewers	The main conclusion of the study, by the reviewers

Table S2.3: Description of study design, development phase, behaviour change techniques, theory or principle, outcome variable, outcomes measures and outcome.

Reference	Study design	Development phase	Behavior change technique	Theory	Outcome variable	Outcome measure	Outcome[A]
[17]	Three-armed RCT	Piloting	'Goal setting (behavior)', 'information about health consequences', 'instruction on how to perform the behavior', 'review behavior goals', 'problem solving', 'self-monitoring of behavior' and 'social reward'	Behavioral therapy, Cognitive Behavioral Therapy, Social Learning Theory and Transtheoretical Model	Behavior	Pedometer and self-report[B]	–
					Usage	Logfiles	+
					User satisfaction	Interview[B] and questionnaire	n.a.
[21]	Three-armed RCT	Piloting	n.r.	Stage models of relationships	Behavior	Pedometer and self-report[B]	–
					Usage	Logfiles	+
					User satisfaction	Questionnaire	n.a.
[3]	Two-armed RCT	Piloting	n.r.	Models of human relationships	Behavior	Pedometer	–
					Usability	Interview[B] and questionnaire	n.a.
					Usage	Logfiles	n.a.
					User satisfaction	Interview[B] and questionnaire	n.a.
					Other: well-being	Questionnaire	–
					Other: loneliness	Questionnaire	–
[20]	Two-armed RCT	Evaluation	'Credible source', 'discrepancy between current behavior and goal', 'feedback on behavior', 'goal setting (behavior)', 'social reward', 'information about health consequences', 'self-monitoring of	Motivational Interviewing	Behavior	Self-report	–
					Knowledge	Questionnaire	–
					Motivation	Questionnaire	+
					Usability	Questionnaire	+ (d=0.38)
					Usage	Logfiles	+ (d=0.38)
					Other: BMI	Calibrated scale	+

			'behavior' and 'social support (unspecified)'				
[4]	Two-armed RCT	Piloting	'Feedback on behavior' and 'goal setting (behavior)'	n.r.	Usage User satisfcation	Logifles Questionnaire	n.a. n.a.
[22]	Two-armed RCT	Development	n.r.	n.r.	Behavior Usage User satisfaction Other: dishonest	Pedometer Logfiles Questionnaire Questionnaire	n.a. n.a. n.a. n.a.
[23]	Two-armed RCT	Evaluation	'Commitment', 'goal setting (behavior)', 'information about health consequences, 'non-specific reward', 'problem solving', 'self-monitoring of outcome of behavior', 'social reward' and 'social support (unspecified)'	Behavioral therapy and Social Cognitive Theory	Behavior Usage User satisfaction Other: weight	Pedometer and questionnaire[B] Logfiles Questionnaire Calibrated scale and questionnaire[B]	+ – – –
[24]	Pretest-posttest design without control group	Piloting	'Information about health consequences'	Patient-centered care and Transtheoretical Model	Motivation Usability Usage User satisfaction	Questionnaire Questionnaire Logfiles Questionnaire	n.a. n.a. n.a. n.a.
[18]	Pretest-posttest design without control group	Piloting	'Feedback on behavior', 'goal setting (behavior)', 'information about health consequences', 'non-specific reward', 'problem solving', 'self-monitoring of outcome of behavior' and 'social support (practical)'	Behavioral change theory and Cognitive Behavioral Therapy	Behavior Usage User satisfaction Other: safety	Walking test Logfiles Questionnaire Phone calls	n.a. n.a. n.a. n.a.

[19]	Four-armed RCT	Piloting	'Feedback on behavior', 'goal setting (behavior)', 'information about health consequences', 'monitoring of behavior' and 'social reward'	Social Cognitive Theory and Transtheoretical Model	Behavior Motivation Usage Usability User satisfaction Other: safety	Questionnaire Questionnaire Logfiles n.r. Questionnaire n.r.	+ (d=1.2) + (d=0.6 - 1.2) n.a. n.a. n.a. n.a.
[25]	Four-armed RCT	Piloting	'Action planning', 'goal setting (behavior)', 'information about health consequences', 'problem solving', 'review behavior goals' and 'reviewing progress'	Motivational Interviewing, Social Cognitive Theory and Transtheoretical Model	Behavior Usability User satisfaction Other: weight	Pedometer and questionnaire[B] Questionnaire Interview and questionnaire[B] Calibrated scale	n.r. n.a. n.a. –
[26]	Two-armed pseudo-RCT	Piloting	'Action planning', 'demonstration of the behavior', 'information about health consequences', 'instruction on how to perform the behavior', 'social reward, problem solving' and 'verbal persuasion about capability'	Mindfulness Based Stress Reduction	Knowledge Motivation Usage User satisfaction	Questionnaire Questionnaire Logfiles Questionnaire	n.r. n.r. + ($d > 1.2$) n.r.
[27]	Two-armed RCT	Evaluation	'Goal setting (behavior)', 'problem solving', 'reviewing progress', 'self-monitoring of outcome of behavior', 'social reward' and 'social support (practical)'	n.r.	Behavior Usage User satisfaction Other: adverse events	Pedometer Logfiles Questionnaire n.r.	+ n.a. n.a. n.a.

[32]	Three-armed RCT	Evaluation	'Goal setting (behavior)', 'problem solving, information about health consequences' and 'verbal persuasion about capability'	Motivational Interviewing	Behavior User satisfaction	Questionnaire Questionnaire	+ n.a.
[28]	Two-armed RCT	Piloting	'Action planning', 'goal setting (behavior), 'information about health consequences', problem solving and 'social support (practical)	Motivational Interviewing and Transtheoretical Model	Behavior Usage User satisfaction	Questionnaire Logfiles Questionnaire	+ n.a. n.a.
[33]	Three-armed RCT	Piloting	'Feedback on behavior', 'self-monitoring of behavior' and 'social support (practical)'	Transtheoretical Model	Behavior Usability Usage User satisfaction	Activity monitor Questionnaire Logfiles Interview[B] and questionnaire	– n.a. n.a. –
[29]	Cluster RCT (report on design)	Evaluation	'Feedback on behavior', 'goal setting (behavior)', 'non-specific reward', 'self-monitoring of behavior', 'social reward' and 'social support (unspecified)'	Social Cognitive theory and Transtheoretical Model	n.a.	n.a.	n.a.
[30]	Two-armed RCT	Piloting	'Action planning', 'demonstration of the behavior', 'goal-setting (behavior)', 'information about health consequences', 'instruction on how to perform the behavior', 'problem solving' and 'social support (practical)'	Motivational Interviewing, self-management and shared decision-making	Behavior Knowledge Usage User satisfaction Other: feasability Other: stress management techniques	Interview Interview Logfiles Interview[B] and questionnaire Recruitment Questionnaire	– – n.a. – n.a. –

[5]	Pretest-posttest design without control group	Piloting	'Feedback on behavior', 'goal setting (behavior)', 'information about health consequences', prompts/cues', 'punishment', 'self-monitoring of behavior', 'self-monitoring of outcome of behavior', social reward, 'social support (practical)' and 'social support (unspecified)'	Goal-setting, Persuasive System Design model and Self-determination theory	Motivation Usage User satisfaction Other: stress	Questionnaire Interview Focus group[B] and interview Questionnaire	n.a. n.a. n.a. n.a.
[31]	Pretest-posttest design with control group	Evaluation	'Feedback on behavior', 'goal setting (behavior)', 'prompts/cues', 'problem solving', 'self-monitoring of behavior, 'social reward', 'social support (emotional)', 'social support (practical)' and 'verbal persuasion about capability'	Transtheoretical Model	User satisfaction Other: reason for participation	Interview Interview	n.a. n.a.

[A] Outcome indicates whether there was a significant positive difference between intervention group with and control group without an embodied conversational agent.
[B] This outcome measure was seen as less objective, and was therefore disregarded.

Abbreviations:
BMI = Body Mass Index
RCT = Randomized Controlled Trial
N.a. = Not applicable
N.r. = Not reported

Chapter 3

Table S3.1: Codebook.

Theme	Category	Subcategory
Food	Healthy living	Bodily functions, mental functions and perception, spiritual and existential health, quality of life, social and societal participation, daily functioning
	Healthy eating	More fruit and vegetables, fresh and natural foods, balance and variety, nutrient, low fat, less red meat and meat products or more white meat and fish, less sugar, more stables or fiber, mindful eating, more or less drinks, own opinion, benefits healthy eating, other
	Food choice	Lack of time, self-control, resistance to change, food preparation, cost of food, unpleasant foods, influence of other people, lack of knowledge or expert consensus, selection influences, limitations of aging, hunger, prescribed diet, other
	Tips and advice	Goals and action planning, feedback and monitoring, social support, associations, substitution, reward and punishment, self-confidence, other
Intervention	Source	Family member, someone familiar, professional, not a person, other
	Medium	Signal, voice, visual, other
	Dialogue	Frequency, tone of voice, timing, other
ECA	General	First impression, surrounding, device
	Appearance	Species, realism, specifications, other
	Background	Name, social relationship, personality, other
Other	About the study	Diary, session
	Influence of the researcher	Influence of the researcher
	Technological knowledge	Technological knowledge
	Other	Other

Chapter 4

Figure S4.1: Mock-ups used for the module cooking.

Figure S4.2: Mock-ups used for the module food.

Figure S4.3: Mock-ups used for the module loneliness.

Table S4.1: Codebook.

ECA	Category	Code
Ellen	Appearance	Accessories, age, BMI, eye color, gender, haircut, outfit, skin color, other
	Background	Family, hobbies, job, living situation, name, partner, political preferences, other
	Content dialogues	Content, formality, sentence length, small talk, use of language, other
	Other	Fit agent and content, personality, other
Herman	Appearance	Accessories, age, BMI, eye color, gender, haircut, outfit, skin color, other
	Background	Family, hobbies, job, living situation, name, partner, political preferences, other
	Content dialogues	Content, formality, sentence length, small talk, use of language, other
	Other	Fit agent and content, personality, other
Bo	Appearance	Accessories, age, BMI, eye color, gender, haircut, outfit, skin color, other
	Background	Family, hobbies, job, living situation, name, partner, political preferences, other
	Content dialogues	Content, formality, sentence length, small talk, use of language, other
	Other	Fit agent and content, personality, other
Unknown	Content dialogues	Content, formality, sentence length, small talk, use of language, other
Other	Other	Other

Summary

The ageing of the global population is the most important medical and social demographic problem worldwide. Promoting health, especially regarding nutrition and loneliness, among older adults can contribute to an increase in healthy life years and life expectancy. eHealth services can be used to deliver such interventions. However, they are often not tailored and persuasive enough to be effective. Embodied Conversational Agents (ECAs) are known to improve the persuasiveness of eHealth services. Studies among older adults show high ratings of acceptance, enjoyment, and usability, but evidence regarding their effectiveness and working mechanisms is limited. Therefore, the aim of this thesis was to provide insight into how to design and evaluate ECAs that support healthy living. The following sub-questions were formulated:

- How are ECAs designed and evaluated?
- How should ECAs support older adults with healthy eating?
- Do matching topics and appearances effect ECAs' personality characteristics and persuasiveness?
- How should PACO be evaluated?
- What factors influence the use and effect of ECAs?

Chapter 2 explored the current practices in designing and evaluating ECAs in the health domain. The Arksey and O'Malley framework was used to conduct a scoping review. The results showed that ECAs most often targeted physical activity and had the appearance of a middle-aged African–American woman. Regarding content, multiple behavior change techniques and theories or principles were applied, but their interpretation and application were usually not reported. During the development process, human-centered and stakeholder-inclusive design approaches tended not to be used. Regarding evaluation, a combination of efficacy and use-related outcomes were assessed, usually in an RCT. However, rather than evaluating specific components, the interventions were evaluated as a whole. Overall, the studies suggested that ECAs for coaching people in relation to a healthy lifestyle can make an intervention more engaging, although evidence on their effectiveness on health remained inconclusive.

Chapter 3 marks the start of the development of PACO. This chapter described a co-creation process with older adults that informed both the content and the appearance of the ECA. Data were gathered through three consecutive iterations of co-design sessions with two groups of community-dwelling older adults in the Netherlands. The first main finding was that older adults approach eating from a holistic perspective. This meant that they evaluated eating not only in terms of nutrients, ingredients, or components, but also in terms of eating mindfully and in a well-balanced way. Second, action planning and self-monitoring were the preferred approaches towards changing eating behavior among older adults. The third and last main finding was that ECAs have the potential to support older adults with healthy eating behaviors in an engaging manner. Next, the requirements for the ECA were discussed. There were five preferred personality characteristics: friendly,

warm, trustworthy, concerned, and competent. The communication style should contain some humor and non-judgmental language.

The design of the ECA was further discussed in **Chapter 4**, which described a study with the goal of identifying the effect of personality characteristics and persuasiveness on a match between the ECA and the health topic. Via an online experiment, three different ECAs (a peer, a cook, and a fantasy figure) and three different health topics (cooking, food, and loneliness) were tested, and the results were triangulated with qualitative insights from a focus group. The results revealed that older adults preferred an ECA whose appearance matched a certain health topic, and this design scored high ratings on persuasiveness and intention to use. However, positive personality traits were not appreciated better as a result of a match. In a focus group, it was explored how both design and personality evaluations should be further improved. Multiple specific design changes were made, and two background stories were developed, together with a list of requirements for the tone of voice in the dialogue script.

The protocol to evaluate the use and the effect on health behavior change of PACO, an extensive description of PACO, and the design process were presented in **Chapter 5**. In addition, two conceptual models were created – one for use and one for effect. The conceptual model explaining ECA use has usability and perceived usefulness as the main predictors for use, which is expected to lead to an improved relationship with the ECA. Good aesthetics are further expected to lead to an improved usability. Enjoyment, privacy concerns, and perceived control are expected to lead to a higher score on perceived usefulness. The conceptual model explaining health effects has the different behavior change techniques as predictors for the three basis psychological needs (autonomy, competence, and relatedness). An improvement in satisfying these needs is expected to lead to improved eating behavior and fewer feelings of loneliness, all of which is expected to lead to an overall improvement in quality of life.

The results of the summative evaluation and the verification of the conceptual models were described in **Chapter 6**. The results showed a significant correlation between use in minutes on the one hand and perceived usefulness and enjoyment on the other. However, these did not predict use in the full regression model. Additionally, PACO use did not lead to improvements in eating behavior or a decrease in loneliness. The study did not provide conclusive evidence about factors that were linked to the use or health effects of ECAs.

Chapter 7 presented the main conclusion and practical guidelines and reflected critically on the work presented in this thesis. In conclusion, this thesis showed that an ECA can be used as a tool to increase users' engagement with an eHealth intervention. Moreover, this thesis provided a use-case of how to develop such an ECA: via a human-centered and stakeholder-inclusive design approach, incorporating grounded behavioral theory, operationalized via various behavior change techniques. Furthermore, this thesis showed how to evaluate an ECA intervention: by developing conceptual models, focusing on both the use and the effect, and combining qualitative, quantitative, and log data.

Samenvatting

De vergrijzing van de wereldbevolking is wereldwijd het belangrijkste medische en sociaal-demografische probleem. Het bevorderen van gezondheid bij ouderen, kan bijdragen aan meer gezonde levensjaren en een hogere levensverwachting. eHealth diensten kunnen worden gebruikt om dergelijke interventies voor gezondheidsbevordering te leveren, al zijn ze vaak niet op maat gemaakt en niet overtuigend genoeg om gezondheidsgedrag te kunnen bevorderen. Van Embodied Conversational Agents (ECAs) is bekend dat ze de overtuigingskracht van eHealth diensten kunnen vergroten. Studies met ouderen laten hoge scores zien voor acceptatie, plezier en bruikbaarheid. Bewijs voor de effectiviteit en werkingsmechanismen is echter beperkt. Daarom heeft dit proefschrift als doel inzicht te verschaffen in het ontwerpen en evalueren van ECAs die een gezonde levensstijl ondersteunen. De volgende deelvragen zijn geformuleerd:

- Hoe worden ECAs ontworpen en geëvalueerd?
- Hoe moeten ECAs ouderen ondersteunen bij gezond eten?
- Hebben matchende gezondheidstopics en verschijningen invloed op de persoonlijkheidskenmerken en overtuigingskracht van ECAs?
- Hoe moet PACO worden geëvalueerd?
- Welke factoren beïnvloeden het gebruik en effect van ECAs?

Hoofdstuk 2 onderzocht de huidige praktijken in het ontwikkelen en evalueren van ECAs in het gezondheidsdomein. Het raamwerk van Arksey en O'Malley- werd gebruikt om een Scoping Review uit te voeren. De resultaten van de review toonden aan dat ECAs zich meestal richten op fysieke activiteit en het uiterlijk hadden van een Afro-Amerikaanse vrouw van middelbare leeftijd. Met betrekking tot de inhoud zagen we dat meerdere gedragsveranderingstechnieken en theorieën of principes toegepast werden, maar dat de interpretatie en toepassing van die technieken en theorieën meestal niet werden gerapporteerd. Tijdens het ontwikkelingsproces werden mensgerichte en stakeholder-inclusieve ontwerpbenaderingen vaak niet gebruikt. Met betrekking tot de evaluatie van ECAs werd een combinatie van effectiviteit en gebruiksgerelateerde uitkomsten onderzocht, meestal in een gerandomiseerde trial. Vaak werd, in plaats van specifieke componenten te evalueren, de interventie als geheel geëvalueerd. Over het algemeen suggereren de onderzoeken dat ECAs voor het coachen van mensen in een gezonde levensstijl een interventie aantrekkelijker kunnen maken, hoewel bewijs voor hun effectiviteit op leefstijl niet overtuigend bleek.

In **Hoofdstuk 3** werden de eerstes tappen voor de ontwikkeling van PACO gezet. Dit hoofdstuk beschrijft een co-creatieproces met ouderen, waarin zowel de inhoud als het uiterlijk van de ECA is bepaald. Data werd verzameld via drie co-designsessies met twee groepen thuiswonende ouderen in Nederland. De eerste bevinding was dat ouderen voeding vanuit een holistisch perspectief benaderen. Dit betekent dat ze eten niet alleen evalueerden in termen van voedingsstoffen, ingrediënten of componenten, maar in termen van bewust en evenwichtig eten. Ten tweede waren het maken van actieplannen en het zelf bijhouden van voedselinname de voorkeursbenaderingen voor het veranderen van eetgedrag

bij ouderen. De derde en laatste belangrijke bevinding was dat ECAs het potentieel hebben om oudere volwassenen met gezond eetgedrag op een overtuigende manier te ondersteunen. Vervolgens hebben we de voorkeuren voor de ECAs besproken. Er waren vijf persoonlijkheidskenmerken die de voorkeur hadden: vriendelijk, warm, betrouwbaar, betrokken en deskundig. De communicatiestijl moest wat humor en niet-oordelende taal bevatten.

Het ontwerp van de ECA werd verder besproken in **Hoofdstuk 4**, waarin een onderzoek werd beschreven met als doel het effect van persoonlijkheidskenmerken en overtuigingskracht op een match tussen ECA en het gezondheidsonderwerp te identificeren. Via een online experiment werden drie verschillende ECAs (een leeftijdsgenoot, een kok en een fantasiefiguur) en drie verschillende gezondheidsthema's (koken, eten en eenzaamheid) getest en werden de resultaten verder aangevuld met kwalitatieve inzichten uit een focusgroep. Uit de resultaten bleek dat ouderen de voorkeur gaven aan een ECA met een uiterlijk dat past bij een bepaald gezondheidsonderwerp, wat resulteerde in hogere beoordelingen op overtuigingskracht en gebruiksintentie. De persoonlijkheidskenmerken werden echter niet beter gewaardeerd als gevolg van een match. In een focusgroep werd verkend hoe zowel het ontwerp als de persoonlijkheid verder verbeterd zouden kunnen worden. Er zijn meerdere specifieke ontwerpwijzigingen doorgevoerd en er zijn twee achtergrondverhalen ontwikkeld, samen met een lijst met eisen voor de toon in het dialoogscript.

Het protocol om het gebruik en het effect van PACO op gedragsverandering te evalueren, een uitgebreide beschrijving van het PACO project en het ontwerpproces van de ECAs staan beschreven in **Hoofdstuk 5**. Daarnaast zijn er twee conceptuele modellen ontwikkeld voor zowel het gebruik als effect van ECAs. In het conceptuele model dat het gebruik van de ECA verklaart, zijn gebruiksvriendelijkheid en ervaren nut de belangrijkste voorspellers voor gebruik, welke naar verwachting zullen leiden tot een verbeterde relatie met de ECA. Verder wordt verwacht dat een goede esthetiek zal leiden tot een verbeterde gebruiksvriendelijkheid. Plezier, zorgen rondom privacy en ervaren controle leiden naar verwachting tot een hogere score op ervaren nut. Het conceptuele model dat gezondheidseffecten verklaart heeft de verschillende technieken voor gedragsverandering als voorspellers voor de drie psychologische basisbehoeften (autonomie, competentie en verbondenheid). Een verbetering van deze behoeften zal naar verwachting leiden tot een beter eetgedrag en minder gevoelens van eenzaamheid, wat naar verwachting zal leiden tot een algehele verbetering van de kwaliteit van leven.

De resultaten van de summatieve evaluatie en de verificatie van de conceptuele modellen zijn beschreven in **Hoofdstuk 6**. De resultaten lieten een significante correlatie zien tussen gebruik in minuten enerzijds en ervaren nut en plezier anderzijds. Nut en plezier voorspelden echter geen gebruik in het volledige regressiemodel. Daarnaast leidde het gebruik van PACO niet tot verbetering van eetgedrag of een afname van eenzaamheid. Concluderend leverde het onderzoek geen sluitend bewijs voor factoren die verband houden met het gebruik of de gezondheidseffecten van ECAs.

Hoofdstuk 7 presenteert de belangrijkste conclusies, praktische ontwerprichtlijnen en reflecteert kritisch op het werk dat in dit proefschrift werd gepresenteerd. Dit proefschrift heeft aangetoond dat een ECA gebruikt kan worden als hulpmiddel om de betrokkenheid van gebruikers bij een eHealth interventie te vergroten. Bovendien liet dit proefschrift zien hoe een ECA ontwikkeld kan worden: via een mensgerichte en stakeholder-inclusieve ontwerpbenadering, met gefundeerde gedragstheorie, geoperationaliseerd via verschillende gedragsveranderingstechnieken. Verder liet dit proefschrift zien hoe een ECA interventie geëvalueerd kan worden: door conceptuele modellen te ontwikkelen, gericht op zowel het gebruik als het effect, en door kwalitatieve, kwantitatieve en loggegevens te combineren.

Dankwoord

Dankwoord

Bedankt voor de tijd die je neemt om dit proefschrift te lezen. Of je nou meteen doorbladert naar het dankwoord, op zoek bent naar de samenvatting of alles (!) hebt gelezen. Ik heb er bewust voor gekozen om het niet 'mijn' proefschrift te noemen. Als er iets is wat ik heb geleerd, is het namelijk dat je een proefschrift nooit alleen schrijft. Het is juist op die eenzame momenten achter je laptop, dat je beseft dat je de hulp van anderen nodig hebt. Of het nou een veel te lange koffiepauze is met collega's, een spontane wandeling met een vriendin, of een discussie met een onbekende, alleen met de hulp van anderen heeft dit proefschrift tot stand kunnen komen. Daarom wil ik hierbij graag iedereen enorm bedanken voor zijn of haar steun, in welke vorm dan ook.

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PACO. Silke, naast projectgenoot, ook nog eens co-auteur op meerdere artikelen. Ik vond het erg fijn om met jou samen te mogen werken. Marije Blok en Eva Siderakis van het Nationaal Ouderenfonds, bedankt voor jullie samenwerking, en het behartigen van de belangen van deze mooie doelgroep. Tot slot WAAG, bedankt voor jullie creatieve inbreng, het is dankzij jullie dat de focusgroepen zo'n positief karakter hebben gekregen. Sanne Muiser, Paulien Melis en Jurre Ongering, bedankt voor de fijne samenwerking. Naast de leden van het projectteam, wil ik ook graag alle studenten bedanken die hun thesis bij PACO hebben geschreven, en zo hebben geholpen om de studies uit te kunnen voeren, en extra inzages te verzamelen. Tot slot wil ik graag alle deelnemers bedanken, zonder uw bijdrage had dit proefschrift niet tot stand kunnen komen. Vooral de focusgroepen hebben veel indruk op mij gemaakt, waarbij de positiviteit erg opvallend was. Maar ook tijdens de evaluatiestudie, waarbij ik de volgende, terechte, opmerking nooit meer zal vergeten: 'ik mag dan wel oud zijn, ik ben niet achterlijk!'. Een opmerking die een perfect antwoord geeft op de eeuwige vraag of ouderen wel met technologie kunnen omgaan.

Jenna Clark, it was a real pleasure working with you on both the evaluation of PACO and Actify. Although the fact that we couldn't meet in real life was one of the biggest disasppointments of my PhD. Thank you for all your support and lessons, I hope our paths will cross again.

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About the author

Curriculum Vitae

Lean L. Kramer was born on September 3, 1994 in Terkaple, the Netherlands. In 2011, she finished secondary school at Bornego College in Heerenveen. After finishing the first year of Facility Management at the Hanzehogeschool Groningen, Lean started with her Bachelor Psychology at the Faculty of Behavioural and Social Sciences of the University of Groningen, where she also worked as a research assistant. She specialized in health psychology and completed the minor Five Big Issues in Health at the Vrije Universiteit Amsterdam. After obtaining her bachelor's degree, she developed special interest in the use of eHealth to support a healthy lifestyle. In 2016, she started with the Master Health Psychology and Technology at the University of Twente. She did an internship at the Faculty of Medical Sciences at the Groningen University Hospital, where she was involved in a research project studying the development of an eHealth application to combat fatigue among cancer patients. She used the Intervention Mapping approach to evaluate the development process and developed a protocol for the evaluation of logdata. Lean her Masterthesis was about the participatory development of a persuasive eHealth tool to support COPD self-management, performed within the start-up company Medicine Men. After obtaining her master's degree, Lean started in 2018 as a PhD Candidate at the Strategic Communication Group at Wageningen University & Research. Her PhD research was part of the three-year PACO project which was funded by ZonMw. The project was lead by Emely de Vet, who initiated the chair group Consumption and Healthy Lifestyles in 2019; Lean continued her PhD project at this chair group. In addition, Lean worked for one day a week at Roessingh Research and Development in Enschede, where she worked together with various project partners. Lean was a member of the PhD Council of the Wageningen School of Social Sciences (2020-2021). During her PhD, she was also involved in teaching, supervising thesis students, and presenting her work at international conferences.

List of publications

L. L. Kramer, S. Ter Stal, B. C. Mulder, E. de Vet, and L. van Velsen. "Developing Embodied Conversational Agents for Coaching People in a Healthy Lifestyle: Scoping Review". *Journal of Medical Internet Research* 22.2 (2020), e14058. DOI:10.2196/14058.

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L. L. Kramer, M. Blok, L. van Velsen, B. C. Mulder, and E. de Vet. "Supporting eating behaviour of community-dwelling older adults: co-design of an embodied conversational agent". *Design for Health* 5.1 (2021), 120-139. DOI:10.1080/24735132.2021.1885592.

L. L. Kramer, B. C. Mulder, L. van Velsen, and E. de Vet. "Use and Effect of Web-Based Embodied Conversational Agents for Improving Eating Behavior and Decreasing Loneliness Among Community-Dwelling Older Adults: Protocol for a Randomized Controlled Trial". *JMIR Research Protocols* 10.1 (2021), e22186. DOI:10.2196/22186.

Completed Training and Supervision Plan

Wageningen School of Social Sciences (WASS)

Lean L. Kramer

Wageningen School of Social Sciences

Name of the learning activity	Department/Institute	Year	ECTS[A]
A) Project related competences			
The Essentials of Scientific Writing and Presenting	Wageningen in 'to Languages	2018	1.2
Good Clinical Practice	Tapas	2018	1.0
Gamified Design	ESD	2019	0.3
Research proposal writing	WUR	2019	6.0
Introduction course	WASS	2019	1.0
Food, Nutrition and Health Program	WUR	2019	2.5
Human-Computer Interaction	The Georgia Institute of Technology	2019	5.0
Symposium Conversational Agents in Gezondheidscommmunicatie	Amsterdam Center for Health Communication	2019	0.2
Review 'Optimizing Child Nutrition Education With the Foodbot Factory Mobile Health App: Formative Evaluation and Analysis'	JMIR	2019	1.0
'Developing Embodied Conversational Agents for Healthy Lifestyles: a scoping review'	ARPH, Egmond aan Zee, The Netherlands	2019	1.0
'Co-design with Elderly: Nutrition and Virtual Coaches'	ClickNL, Eindhoven, the Netherlands	2019	1.0
Design thinking and Making for the Humanities	RMeS	2020	5.0
Symposium Digital Health: Weerstand of motivatie?	Amsterdam Center for Health Communication	2020	0.2
Review 'Feasibility and acceptability of using a digital health agent to deliver online brief motivational interviewing for alcohol misuse'	JMIR	2020	1.0
'Embodied Conversational Agents coaching older adults towards dietary behavior change'	ARPH, Egmond aan Zee, The Netherlands	2020	1.0
'Engaging co-design for engaging Embodied Conversational Agents'	UCL, London, United Kingdom	2020	1.0

B) General research related competences			
Philosophy of Technology and Design	University of Twente	2019	0.4
Seminar Decision making and the food system	WASS	2019	0.5
High Tech for a Sustainable Future	4TU. Federation	2019	0.15
Wageningen PhD Symposium	WPS	2019	0.3
Basic Statistics	PE&RC	2019	1.5
Sustainable Tourism	WUR	2020	3.5
Interview in local newspapers	BDU Media	2020	0.5
Popular Science Writing	WASS	2021	1.5
C) Career related competences			
PhD Workshop Carousel 2018	WGS	2018	0.3
Brain friendly working and writing	WGS	2019	0.3
Teaching assistant BSc coucres and supervision BSc and MSc theses	COM and CHL, WUR	2018-2021	4.0
PhD Council	WASS	2020-2021	2.0
Total			**43.35**

[A] One credit according to ECTS is on average equivalent to 28 hours of study load.

Colophon

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