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Virtual Coaches for Older Adults' Wellbeing: A Systematic Review

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ABSTRACT Virtual Coaches, also known as e-coaches, are a disruptive technology in healthcare. Indeed, among other usages, they might provide cost-effective solutions for increasing human wellbeing in different domains, such as physical, nutritional, cognitive, social, and emotional. This paper presents a systematic review of virtual coaches specifically aimed at improving or maintaining older adults' health in the aforementioned domains. Such digital systems assume various forms, from classic apps, to more advanced conversational agents or robots. Fifty-six articles describing a virtual coach for older adults and aimed at improving their wellbeing were identified and further analyzed. In particular, we presented how previous studies defined their virtual coaches, which behavioral change models and techniques they adopted and the overall system architecture, in terms of monitoring solutions, processing methods and modalities for intervention delivery. Our results show that few thorough evaluations of e-coaching systems have been conducted, especially regarding multi-domain coaching approaches. Through our analysis, we identified the wellbeing domains that should be addressed in future studies as well as the most promising behavior change models and techniques and coaching interfaces. Previous work illustrates that older adults often appreciate conversational agents and robots. However, the lack of a multidomain intervention approach in the current literature motivates us to seek to define future solutions.

INDEX TERMS Older adults, review, virtual coach, wellbeing, e-coach.

I. INTRODUCTION

Due to longer life expectancy and declining fertility rates in most developed countries, the proportion of people aged over 65 years is growing faster. By 2030, it is expected that the proportion of people aged 65 and over will raise from 17.4% to 25.6%. Some forecasts suggest that the population of older adults will almost double from 87.5 million in 2010 to 152.6 million in 2060 [57]. As people generally live longer, maintaining cognitive and physical autonomy of older adults, and thus their independence, is a key challenge that all modern societies must face and succeed to ensure the economic and social wellbeing of the entire population. In the past decades, promoting the wellbeing of older adults often required costly interventions, especially in terms of human resources. Nowadays, technology-based interventions to improve healthcare and to promote healthy lifestyles are a tangible reality and they represent an important opportunity to foster healthy aging at a larger scale. In particular, the advances and diffusion of mobile technologies

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(i.e., smartphones and connected objects), artificial intelligence and robots paved the way for the development of virtual coaches or e-coaches, which are able to support, complement, and possibly replace human coaches in health interventions. A definition of e-coaches has been provided in 2018 by Banos and Nugent [61] while typical e-coaching architectures are illustrated by Ochoa and Gutierrez [62] in the same year. In 2017, Lentferink *et al.* [58] conducted a scoping review in order to individuate the key component in e-coaching interventions. However, their review focused only on studies conducted on the working age population, excluding studies conducted in samples of older adults. As virtual coaches for older adults are becoming not only possible, but have been individuated and supported by the European Commission [60] as a possible relief for the aging society.

We conducted a systematic review on previous work in the field of e-coaches for older adults, with a particular focus on digital interventions for promoting healthy lifestyles. In this systematic review, we explored the different definitions that have been previously used to describe a "virtual coach" and/or a "companion" and we analyzed the previous systems conceived to support wellbeing in older users. In addition, we studied the existing architectures used to monitor, process and deliver data to older adult users, the adopted behavior changes models and techniques and the results obtained in each study. In this review, we limited our search to papers specifically related to our target population (people aged 65 years and older). A list of keywords was used to search four notable databases encompassing journals and conference publications in the areas of life science, bioengineering, and informatics. Using the PRISMA flow diagram, we identified 490 articles; 56 articles were deemed suitable for the present analysis. Each paper was analyzed by at least two partners from the NESTORE project [67] based on their relevant expertise in the reviewed domain, in order to answer our research objectives (see Section II). The NESTORE project aims to design a virtual coach for promoting healthy lifestyle and improving or maintaining the wellbeing of older adults in different domains [70]. The remainder of this paper is structured as follows: Section II details the objectives of our systematic review; Section III presents the reviewing methodology; Section IV presents the results; Section V discusses the implications of the findings and further research pathways and, finally, Section VI concludes this review.

II. OBJECTIVES OF OUR SYSTEMATIC REVIEW AND RESEARCH QUESTIONS

The main aim of this paper is to review the works that propose virtual coaches/companions conceived to improve older adults' wellbeing. We considered all works targeting the physical, nutrition, cognitive, social, and emotional domain with a particular focus on multi-domain studies. We did not include coaches for rehabilitation or treatment purposes of particular conditions, because our research purpose focuses particularly on healthy older adults in general. In order to carry out this review, we defined 4 research questions.

A. Q1. WHICH ARE THE DIFFERENT DEFINITIONS FOR "COACH" AND "COMPANION"?

The first objective of our systematic literature review is to get a better understanding of how previous eHealth studies defined and used the terms "coach" and "companion".

B. Q2. WHICH BEHAVIOR CHANGE MODELS (BCMs) AND BEHAVIOR CHANGE TECHNIQUES (BCTs) WERE USED?

The second objective is to identify which BCMs have been adopted in virtual coaches and companions for older adults (if any) and how these models have been translated into digital interventions through specific implementations of the BCTs.

C. Q3. HOW ARE DIFFERENT DOMAINS TACKLED IN PREVIOUS STUDIES?

The third objective of our analysis is to identify the domains tackled by the different coaches. This includes the intervention types, the target behaviors and the coaching activities proposed in each domain.

D. Q4. HOW ARE DIFFERENT SYSTEMS IMPLEMENTED IN TERMS OF MONITORING, PROCESSING AND DELIVERING THE INTERVENTION?

The fourth objective of our analysis is to understand how the e-coaching systems were implemented. Inspired by the e-coaching architecture proposed by Ochoa and Gutierrez [62], we focused on the strategies for collecting data (e.g., automatic monitoring, self-reporting, etc.), for processing (e.g., technologies used for activity recognition and for suggesting adapted activities) and for delivering the intervention to the user (e.g., smartphone, app, web app, robot, conversational agent, etc.).

III. E-COACHING FOR OLDER ADULTS REVIEW METHODOLOGY

We conducted a systematic review of scientific studies on e-coaching interventions for improving older adults' wellbeing, with a particular focus on digital systems focused on promoting healthy lifestyles. We used the international guidelines established by PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [60].

A. LITERATURE SEARCH

We ran our search on 4 databases: PubMed, EBSCO, Scopus, and Web of Science. Three sets of keywords have been defined for identifying "virtual coaching systems" targeting "wellbeing" for "older adults".

In order to select studies presenting virtual coaches, even if not defined by the authors as such, we used the following keywords:

K1 = "animated conversational agents" OR "artificial companionship" OR "autonomous robotic agent" OR "coaching system" OR "chatbot" OR "communication robot" OR "conversational agent" OR "conversational agent-based system" OR "conversational partner" OR "digital avatar" OR "digital coach" OR "digital coaching" OR "e-coach*" OR "ecoach*" OR "ecoaching'' OR ''e-coaching'' OR ''Embodied conversational agent'' OR ''home dialogue system'' OR ''relational agents'' OR ''robotic pet'' OR ''robotic psychological assistance'' OR ''screen agent'' OR ''socially communicative machine'' OR ''tutoring system'' OR ''virtual advisor'' OR ''virtual agent'' OR ''virtual assistant'' OR ''virtual carer'' OR ''virtual coach'' OR ''virtual coaching'' OR ''virtual conversational partner'' OR ''virtual companion'' OR ''virtual educator'' OR ''virtual exercise coach'' OR ''virtual expert'' OR ''virtual friend'' OR ''virtual instructor'' OR ''virtual mentor'' OR ''virtual personal trainer'' OR ''virtual therapist'' OR ''virtual tutor''.

To select systems that promote wellbeing and healthy lifestyles, we used the following keywords:

K2 = (''fitness'' OR ''health'' OR ''wellbeing'' OR ''well-being'')

Finally, in order to select systems aimed to older adults, we used the following keywords:

K3 = (''active aging'' OR ''eldercare institutions'' OR ''elderly'' OR ''elderly users'' OR ''grownup'' OR ''older adults'' OR ''older seniors'' OR ''retiree'' OR ''senior''). As a result, the full query for this systematic review was:

K = K1 AND K2 AND K3

Note that the asterisk ''*'' (e.g., in ecoach*) is used to identify all the words that start with ''ecoach'' such as ''ecoaches'', ''ecoaching'', etc. Also, note that the omission or the use of the hyphen ''-'' in any keyword leads to different search results. Hence, ''wellbeing'' and ''wellbeing'' as well as ''ecoach'' and ''e-coach'' were used as separate keywords in the query.

We ran the query on Pubmed, and EBSCO to identify all the articles that contain at least one keyword of a keyword set in the title or abstract. Next, we ran the query in Scopus to identify all the articles that contain at least one of the three types of keywords in the abstract, whereas the search in Web of Science database was by topic. Performing the query in the four aforementioned databases resulted in a total of 470 papers. In addition, a manual search was performed on Google Scholar to identify additional articles using keywords of K1, K2, and K3. Hence, twenty additional papers from this search were added to our pool of selected papers. As a result, we obtained 490 papers. After removing duplicates, our total starting pool consisted of 380 papers.

B. SCREENING

The screening phase aimed at eliminating non-relevant papers by screening the title and abstract and was based on objective exclusion criteria. Exclusion criteria were press articles, unavailable full-text, articles written in any other language but English, and articles not relevant to virtual coaching. After the screening phase, 179 papers were retained.

C. ELIGIBILITY

The eligibility phase aimed at distinguishing relevant full-text papers that comply with the following criteria:

(a) The paper presents a coaching system.

(b) The coaching system consists of a closed loop on the user, which includes a monitoring system through sensors or self-monitoring or other, a processing system for elaborating the data and deciding the intervention and a feedback system to coach the user through apps or emails or robotic interfaces, etc.

(c) The system might include a human component but should include at least a technological component in one of the sub-systems which are the monitoring, processing or intervention delivery.

(d) The system coaches the user for promoting a healthy lifestyle and it is focused on disease prevention but not for therapy, rehabilitation or medication.

(e) The paper does not present a system solely intended for entertaining or leisure such as a social companion. In fact, it has to be coaching at least in one of the relevant domains. Note that a system that helped stop smoking or improved lifestyle in obese people can still be considered in the prevention category.

(f) The target population of the system is older than 65 years old.

Two of the authors of this paper have independently evaluated the eligibility of each paper. A third author further reviewed articles with disagreeing ratings. At this point, eligibility was assigned according to a majority vote rule. As a result, 56 papers were declared as eligible.

D. ANALYSIS

We conducted a qualitative analysis on 56 papers describing the aim, the study type, the definition of companion or coaching, the behavioral change techniques used, the intervention techniques adopted, as well as the coaching domains, the intervention types, and the target behaviors. Finally, we summarized the technologies used for the e-coaching system parts with their intervention frequency and medium. In other words, we analyzed the existing papers based on our research questions mentioned above in Section II. Because of the limited number of Randomized Controlled Trials (RCT) studies found, we could not perform a quantitative statistical analysis on the collected data.

In the next Section (Section IV), the results of our research questions are shown. The PRISMA diagram in Fig. 1 shows the whole process explained above.

IV. RESULTS OF THE SYSTEMATIC REVIEW

A. TYPE OF STUDIES

This section categorizes each article by the type of study. This allows understanding how previous virtual coaches for older adults were designed and how much the results of these studies were reliable and applicable in different contexts. We consider RCT studies as our ground truth to obtain general valid evidence and answers to our research questions. Table 1 shows the type of study of each article.

We found a small portion of papers that describe a gold standard intervention study design of RCT. Hence, because

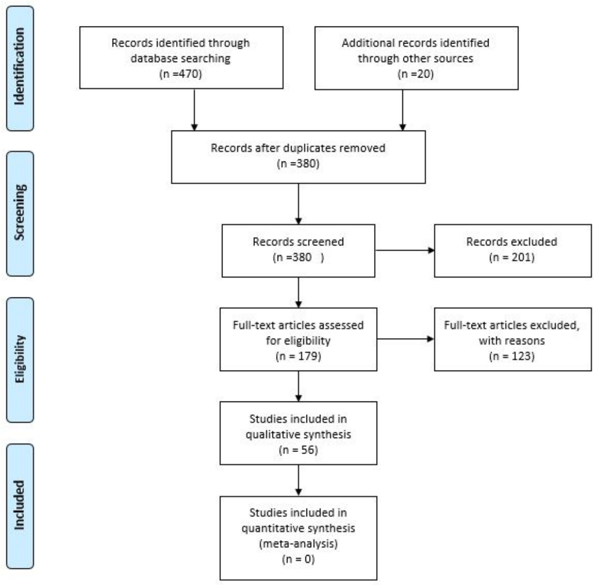

FIGURE 1. Prisma diagram [60].

TABLE 1. Overview of type of studies and paper classification.

TYPE OF STUDY	PAPERS
Randomized trial	[2, 3, 11, 48, 55, 56]
Pilot study	[12, 13, 14, 21, 26, 31, 35, 39, 40, 43, 44, 45, 46, 47, 53, 54]
Observational study	[28, 30]
Preliminary studies for assessing usability or co-design choices	[1, 5, 9, 15, 18, 20, 23, 24, 27, 34, 49]
System proposal (no user study)	[6, 16, 17, 19, 22, 25, 29, 36, 52]
Study protocol	[4, 7, 8, 32, 33, 41]
Field study	[10, 42, 50, 51]
Pre-post intervention study	[38]
Quasi experimental prospective study	[37]

of a limited understanding of how to design and implement e-coaching interventions for older adults, as well as limited evidence regarding their effectiveness in promoting health-related outcomes, we refrained from excluding further papers and kept all 56 for our analysis. In fact, among the 56 papers selected as eligible for the analysis, five reported results of randomized controlled trials [2], [3], [11], [55], [56] and one study was a clinical trial [48], six reported protocols for future randomized trials [4], [7], [8], [32], [33], [41], 16 presented results of pilot studies [12]–[14], [21], [26], [31], [35], [39], [40], [43]–[47], [53], [54] and two were observational studies [28], [30], while [38] presented a pre-post intervention study. Eleven presented the results of a preliminary assessment of a system in terms of usability or co-design choice [1], [5], [9], [15], [18], [20], [23], [24], [27], [34], [49], four [10], [42], [50], [51] presented a field study for deriving the requirements of a coaching system, and nine presented only a proposal of a coaching system or an architectural implementation, without any user study [6], [16], [17], [19], [22], [25], [29], [36], [52]. Finally, a single paper [37] presented a quasi-experimental prospective study. It is worth noting that papers [1], [10], [12], [14], [23], [33], [34], [45], [49]–[51] and [55], [56] were related to the same project, but presenting different versions of the same system. Also, in papers [2], [3], [11], [21] different versions of the same embodied conversational agent were used as intervention medium.

In the next part of this section, we present the results of the review according to the objectives described in Section II.

B. DEFINITION OF VIRTUAL COACHING AND COMPANIONSHIP (RESPONSE TO SECTION II Q1)

Among the 56 papers found during this systematic literature review, two present precise definitions of a virtual coach or virtual companion. In [53], the authors present a clear definition of e-coach referencing another publication [64]. They state that ''Virtual coaches can be understood as computer systems capable of sensing relevant context, determining user intent and providing useful feedback with the aim of improving some aspect of the user's life''. In the same paper, the authors state that the main goal of an e-coach is to support behavior change but in doing so, it assumes different roles, i.e., (1) mentor, (2) friend, and (3) expert. These roles define the main characteristics that an e-coach should present: teaching the user new skills, providing a sense of companionship by establishing an effective relationship based on trust, and providing relevant and accurate information that the user asks for. Another paper [54] provided a specific definition limited to their work, which refers to e-coaches as robots that are supposed to ''facilitate learning and improve cognitive functioning''. In this definition, it is possible to find only the characteristics linked to the e-coach role of a mentor. Although it was possible to retrieve only two definitions from these papers, 19 out of the 56 articles mention some of the characteristics that an e-coach should present. The main activity considered to be part of the e-coach intervention is linked to supporting the user to reach her goal (8 papers). Only a few refer to target behaviors and behavior change techniques. Another fundamental characteristic for an e-coach is the ability to motivate the user, with five papers explicitly referring to this requirement. Another important service that the e-coach should provide is the personalization (sometimes referred to as "tailoring") of the intervention. Finally, one important characteristic reported in these articles (7 out of 56) concerns companionship and the social role that the e-coach should play. In the paper entitled "Using Socially Assistive Human–Robot Interaction to Motivate Physical Exercise for Older Adults" [24], the authors state that an e-coach should present the same qualities as reported in the Companion Animal Bonding Scale items: good, loving, friendly, cuddly, warm, pleasant, kind, sweet, and close. Although it is possible to retrieve these characteristics related to companionship, none of the aforementioned papers provides a specific definition of "companion". The analysis of previous papers, have also helped us to identify different keywords related to the definition of e-coach and companion. For instance, "personalized" appeared three times and it was also referred as "tailored", which appeared once. The keyword "support" appeared ten times, whereas the keyword "motivate" appeared six times. "Companion" appeared seven times. Other keywords that we identified were "advisor" and "change behavior". However, both words only appeared once. We used these keywords to build our own definition of e-coach and companion for older adults' wellbeing, provided in Section V.

C. BEHAVIOR CHANGE MODELS (BCMs) AND INTERVENTION TECHNIQUES (RESPONSE TO SECTION II Q2)

The main goal of analyzing the different models of health behavior change theories used is to understand how a set of psychological constructs can jointly explain how individuals can be motivated to change an established behavioral pattern. The behavioral pattern is based on the interest of improving or maintaining overall long-term wellbeing.

Existing theoretical health-related behavior change models can be distinguished broadly into two types of models: continuum models and stage models. Continuum models, such as the Theory of Reasoned Action [78], Theory of Planned Behavior [79], Social-Cognitive Theory [80], Health Belief Model [81], Protection Motivation Theory [82], describe the degree to which individuals are likely to act; interventions based on such models focus on moving people closer to action. One characteristic of interventions rooted in continuum models is that they mainly target groups of people (instead of subgroups or individuals) and on changing all variables for all individuals, but no tailoring to particular subgroups occurs. Stage models, on the other hand, such as the Transtheoretical Model [83], divide the behavior change trajectory into qualitative and ordered stages, into which individuals can be classified. Within a stage, individuals are more similar than across stages. Thus, they provide a good framework for stage-matched treatments for subgroups of individuals. In the context of intervention research, stage models provide some advantages over continuum models because they are not overgeneralizing to the entire population.

In this systematic review, it became clear that only a minority of papers, i.e., 18 out of the 56 papers included in the review, used or explicitly discussed a theoretical Behavior Change Model (BCM) to support the functioning of the e-coaching system. For the majority of our pool of papers, no such model was referenced. Rather, general psychological theories relating to motivation and wellbeing, e.g., self-determination theory [65], general provision of feedback to participants and the tracking of emotional states as one way of tailoring the intervention under study were mentioned. Eight of the papers [8], [10], [26], [30], [45], [46], [50], [51] referencing any BCM presented the Transtheoretical Model (TTM) of Behavior Change as the conceptual basis for the presented e-coach. Another study used social cognitive theory [29] as a theoretical framework. For instance, in a larger project intended to increase exercise and healthy nutrition intake (i.e., fruit and vegetable consumption) in healthy older adults [8], participants received person-specific intervention materials. This latter also mapped each stage outlined in the TTM. In addition, the definition of an explicit trajectory of stages was a feature of the TTM that led to the authors' decision of using this model as the conceptual framework. A similar approach was used in [26], in which an adapted version of the TTM guided the mathematical modelling of states of behavior and behavior change derived from a multitude of sensor input in a multidomain intervention targeting physical activity, nutrition, sleep, socialization, and cognition. It is interesting to note that a recent review of eHealth interventions targeting physical activity in older adults identified the use of a conceptual framework as a guiding principle for the intervention design in the majority of studies, spanning a wide range of behavior change models [36]. These also included the application of the Health Action Process Approach (HAPA) model [63]. We also found evidence for a greater effectivity of theory-based rather than non-theory-based interventions [36].

In terms of BCT employed across the identified papers in our review, components related to self-efficacy and the Theory of Planned Behavior as well as Self-Determination Theory were identified in two projects [43], [47]. Stages of I-change health behavior models and Fogg's model were identified as guiding BCT selection in another small group of papers [42], [55], [56]. Finally, a single paper [11] incorporated 13 of the 26 behavior change techniques that were identified in the taxonomy by C. Abraham and S. Michie [84].

Table 2 shows the main intervention techniques and features that could affect health outcomes, usability and adherence to the program [58]

- Reduction of activity options by setting short-term goals to eventually reach long-term goals: Goal setting is reduced from the high-level long-term intention making, to specific short-term activities.

TABLE 2. Overview of intervention techniques and paper classification.

INTERVENTION TECHNIQUES	PAPERS
Reduction	[2, 6, 24, 25, 26, 35, 37, 38, 48]
Personalization of goals	[1, 2, 3, 5, 6, 7, 8, 11, 15, 18, 22, 24, 25, 26, 29, 30, 32, 36, 37, 38, 41, 46, 48, 49, 55, 56, 50, 51]
Personalization of content	[2, 3, 4, 5, 6, 10, 11, 12, 16, 17, 19, 20, 23, 24, 25, 26, 28, 29, 30, 32, 33, 38, 40, 41, 43, 46, 47, 48, 49, 50, 55]
Praise	[1, 2, 3, 4, 6, 10, 12, 15, 16, 20, 22, 24, 27, 30, 35, 38, 46, 48, 53, 54]
Reminders	[4, 9, 10, 16, 19, 20, 23, 25, 28, 30, 31, 35, 36,37, 46, 48, 50, 51, 56]
Validity-tested devices	[1, 3, 4, 5, 6, 11, 12, 14, 15, 17, 18, 20, 21, 22, 26, 28, 29, 31, 32, 35, 37, 43, 44, 46, 48, 51, 52, 55]
Self-tracking + e-coaching	[1, 2, 3, 4, 6, 7, 11, 12, 18, 20, 21, 24, 25, 30, 35, 36, 38, 37, 47, 48, 55, 56]
Face-to-face instructions	[7, 8, 10, 11, 12, 14, 18, 21, 26, 31, 32, 45, 48, 56]

- Personalization of goals: intermediate goal thresholds adapted by the system according to user's preferences and states and where users cannot also choose activities from a predefined list
- Praise messages: praise messages are particular rewards that could be provided by the virtual coach.
- Reminders to enter self-reported data into the system.
- Use of validity-tested devices: devices are well chosen and tested that they work.
- Integration of self-tracking and persuasive e-Coaching: self-tracking for user input to enter data or for reviewing activities that are tracked by the system.
- Provision of face-to-face instructions during implementation: whether face-to-face instructions will be considered at the beginning at least in order to make sure users understand.
- Provision of personalized content: whether content will be personalized with respect to local traditions, facilities and culture tolerance.

We found that each paper uses different factors for improving the effectiveness and usability of its study. None of the papers uses all the intervention techniques cited in this analysis. However, from Table 2, we can conclude that the personalization of content is the most frequent technique implemented in the analyzed studies. Examples of content personalization in some research papers are: history of previous interaction of the user [2], [11], [19], [20], [25], [47], barriers negotiation with users [3], [30], ability of users to choose modalities for the interaction [6], [12], content display based on personal needs and preferences [32]–[34], [40], [41], [47], [49], local news information [16], advice and recommendations for behavioral change based on the user's preferences and needs [26], [49]–[51], [55], or other [10], [17], [35]. It is worth noting that articles [24], [34], [38], [53] had a minimized personalization of content (e.g., the system using only the user's name in its communication), and this was considered in the analysis but noted as a low degree of content personalization.

D. COACHING DOMAINS, INTERVENTION TYPES AND COACHING ACTIVITIES (RESPONSE TO SECTION II Q3)

Table 3 shows how the reviewed studies explored the different coaching domains. 28 out of 56 studies proposed a multi-domain approach. Among these studies, only two papers [10] and [50] addressed all the domains (i.e., physical, nutrition, cognitive, social, and emotional), other two [42] and [51] addressed four domains with the exception of the cognitive and emotional domain, respectively. Five papers [9], [13], [21], [36], [47] addressed three domains and all the other multi-domain e-coaches dealt only with two domains, often nutrition and physical activity. It is worth noting that paper [23] presented two different use-cases addressing physical and social coaching but not integrated as a multi-domain coaching intervention. Also, systems that do offer multi-domain coaching, e.g., Matilda [10], a robot for older adult care in residential facilities, provides different coaching activities for each domain, without relying on a multi-domain coaching model. The next subsections will focus on the different coaching domains and in particular on intervention types, target behaviors, and coaching activities adopted for each domain. As mentioned before, intervention types and target behaviors are analyzed according to the categories defined by our experts in each domain.

1) PHYSICAL DOMAIN

Physical activity was included as coaching domain for most of the studies found in this review (44 out of 56). One reason for this may be that physical activity can be reliably measured with little or no obtrusiveness using sensors. In addition, many guidelines exist on the recommended and optimal physical activity behavior in daily life in different age groups. Table 4 shows interventions and target behaviors that addressed the domain of physical activity. Most interventions were oriented to aerobic/endurance

TABLE 3. Overview of coaching domains and paper classification.

DOMAIN	PAPERS
Physical	[1, 2, 3, 4, 6, 8, 9, 10, 11, 12, 14, 15, 17, 18, 20, 21, 22, 23, 24, 25, 27, 28, 29, 30, 32, 33, 34, 35, 36, 37, 38, 39, 40, 42, 43, 44, 45, 46, 47, 48, 50, 51, 55, 56]
Nutrition	[4, 8, 10, 19, 25, 28, 36, 37, 41,42, 44, 46, 50, 51]
Social	[5, 10, 13, 19, 20, 21, 22, 23, 26, 31, 36, 38, 39, 42, 47, 49, 50, 51, 53]
Cognitive	[7, 9, 10, 13, 17, 24, 45, 50, 51, 54]
Emotional	[9, 10, 13, 16, 21, 41, 42, 47, 50, 53, 54]
Multi-domain	[4, 8 ,9, 10, 13, 17, 19, 20, 21, 22, 23, 24, 25, 28, 36, 37, 38, 39, 41, 42, 44, 45, 46, 47, 50, 51, 53, 54]

TABLE 4. Physical domain intervention types and target behaviors.

INTERVENTION TYPES	TARGET BEHAVIORS	PAPERS
Aerobic/Endurance Training;	Retain/Improve Cardio-Respiratory Fitness	[1, 2, 3, 6, 8, 10, 11, 16, 17, 21, 22, 23, 28, 29, 30, 32, 38, 42, 45, 46, 48, 50, 51, 55, 56]
Strength/Resistance Training;	Retain/Improve Strength-Power	[6, 12, 14, 15, 24, 27, 35, 38, 40]
Flexibility Training;	Retain/Improve Flexibility	[6, 12, 14, 15, 27, 38, 42, 43]
Balance Training	Retain/Improve Balance	[12, 14, 27, ,38]
Not clearly specified	Not clearly specified	[4, 18, 20, 25, 33, 34, 36, 37, 39, 41, 44, 47]

training (25 out of 56), although strength/resistance training and flexibility training were also implemented in 9 and 8 studies. Balance training was implemented only in four studies. Target behaviors defined in (Section II, Q3) (i.e., Retain/Improve Cardio-Respiratory Fitness; Retain/Improve Strength-Power; Retain/Improve Flexibility; Retain/Improve Balance) are directly mapped to the respective intervention types; therefore, the same distribution among studies can be found. The analyzed studies did not distinguish between "retain" and "improve" target behaviors; indeed, such distinction usually depends on the fitness level of the user. In 12 papers, intervention types and target behaviors were not specified. Most of the listed studies did not explicitly describe the exercises that are proposed to the users and only some generic conclusions about the coaching activities can be inferred by reading these papers. Among all the papers included in this review, only in a single case [38] the proposed activities/exercises were clearly focused on all of the four subdomains of physical activity. In fact, it proposes activities according to the Otago Exercise Program [66] that is mainly focused on strength and balance but also has some prescriptions concerning flexibility and aerobic activities.

2) NUTRITIONAL DOMAIN

14 articles included nutrition in the coaching activities, but most of them focused on the description of the technological or methodological aspects of the coaching system, leaving the nutritional coaching details in the background or, even, unspecified. However, some general trends could be derived: nutritional coaching interventions are almost all dedicated to improve the user's awareness about healthy diets in order to achieve or/and maintain healthy dietary habits. Only one paper, describing a digital health program for diabetes prevention in people at-risk, directly aimed to support the user in achieving and maintaining an optimal body weight [28]. None of the analyzed papers proposed hyperproteic or hypercaloric diets to address sarcopenia and malnutrition that are common diet-related challenges in aging.

The healthy dietary support is often obtained using an educational intervention, such as providing information to make the diet more compliant with the Mediterranean style [36], suggesting healthy recipes for cooking [37], [41] or, even recommending healthy ingredients such as fruit or vegetables [8], [10]. However, some works proposed more interactive approaches. For instance, the Australian Matilda study employed an assistive communication robot in residential care and home-based care facilities. This system provides timely reminders for drinking [50] and supported user inter-

TABLE 5. Nutritional domain intervention types and target behavior.

INTERVENTION TYPES	TARGET BEHAVIORS	PAPERS
Healthy Dietary Habits;	Achieve/Maintain Healthy Dietary Habits	[36, 37, 41, 42, 44, 46, 50, 51]
Hypocaloric Diet;	Achieve/Maintain Optimal Body Weight	[28]

TABLE 6. Cognitive domain intervention types and target behavior.

INTERVENTION TYPES	TARGET BEHAVIORS	PAPERS
General Cognitive Functioning and Everyday Cognition (Transfer)	Executive Functioning/ Working Memory/ General Cognitive Functioning and Everyday Cognition	[7, 9, 10, 17, 50, 51, 54]
Video Games Intervention for Multiple Cognitive Domains		[7]
Productive Intellectual Engagement for General Cognitive Function and Everyday Cognition		[17]

action to the system diet suggestions [51]. Other approaches, involving the active user participation, proposed discussions about eating habits and eating disorders [44], or asked the user to write eating diaries based on which the system could provide personalized feedback [42] and [46].

3) COGNITIVE DOMAIN

Although cognitive trainings represent a key intervention type and domain in aging research that is not explicitly focused on e-coaching, cognitive activity and functioning were included as a central coaching domain in only 10 out of the 56 studies found in this review [7], [9], [10], [13], [17], [45], [50]–[52], and [54]. Enhancing, maintaining cognitive functioning, or preventing cognitive decline is typically targeted using more structured, computer-based cognitive training interventions and outside the context of "coaching" or "e-coaching" [59], which might explain the lack of studies in the e-coaching field captured in the present review.

The types of interventions that were included in this review are: video game training targeting multiple cognitive domains simultaneously (i.e., multi-domain focus within the cognitive domain) [7], productive intellectual engagement [17], as well as video game training without an explicit multi-domain focus [50] and [51]. The main target of the studies identified in this review was general cognitive functioning (e.g., memory, prospective memory, executive functioning) and everyday cognition [7], [9], [10], [17], [50], [51], [54] or speech abilities [17], as well as delaying the onset of dementia [45].

The main coaching activities incorporated in the papers reviewed are: virtual tasks that mimic everyday tasks [11], tasks performed at the computer [9], quizzes [10], reminders of daily activities [10], story-telling and conversations to enhance speech and memory ability [17], memory games [24], interactive video games [45], general mental activity engagement [50], [51], and reading/math exercises as activities intended to enhance overall cognitive functioning [54].

TABLE 7. Social domain intervention types and target behavior.

INTERVENTION TYPES	TARGET BEHAVIORS	PAPERS
Befriending for Improving the Opportunities for Social Contact and engage user in a conversation;	Improving the opportunities for social contact	[5, 10, 13, 22, 23, 26, 31, 36, 38, 39, 49, 50, 51, 53]
	Enhance Social Skills	[5, 26, 39]
	Enhance Social Support	[10, 21 ,25, 31],
	Reduce Loneliness	[13, 17]

4) SOCIAL DOMAIN

Loneliness is a key challenge in the social domain related to aging. Nonetheless, the e-coaching literature does not (yet) reflect this trend. Social activity was included as a main coaching domain in only 19 of the 56 studies found in this review [5], [10], [13], [19], [20]–[26], [31], [36], [38], [39], [42], [47], [49]–[51] and [53]. Two studies did not explicitly state if they targeted social activity as a key coaching domain [34], [41]. The main intervention types were specifically designed social activities to facilitate (remote) social interactions and befriending [5], [10], [13], [22], [23], [42] or to generally engage the user in a conversation [21], [38], [39], for instance via phone, email, Skype or visits [5], [31]. The main target of these studies was to enhance social skills [5], [26], [39], to improve opportunities for (remote) social contact [5], [10], [13], [22], [23], [26], [31], [36], [38], [39], [49]–[51], [53], to enhance social support [10], [21], [25], [31], and to reduce feelings of loneliness [13], [17]. The main coaching activities in the identified studies are: remote participation in activities (i.e., through a remote companion) or real-life participation in activities enhancing social contact [5], [26], [38], [50], [51], [53], positive engagement and conversations with a companion or real person [10], [17], [19]–[22], [31], [36], [53], multi-user games [10], [26], [39], [50], [51], and encouraging the use of social interactions via phone, email, Skype or visits [13], [23], [26], [42], [47], [49], [50].

5) EMOTIONAL DOMAIN

In recent years, researchers have begun to take the emotional element of coaching into consideration while providing frameworks for e-coaching. Emotional activity or aspects of emotion recognition were included as a coaching domain in 11 of the 56 studies found in this review [9], [10], [13], [16], [21], [41], [42], [47], [50], [53], [54]. A number of these studies use fairly basic conceptualizations of emotions, although there seem to be significant differences across e-coaching systems. Thus, in this review, we examined the main activities used to tackle the emotional domain. Some of the main coaching activities include, for example, the promotion of regular breaks during work and exercises to reduce stress [9], or the systems respond to emotions identified through facial or speech recognition or mood mapping with feedback and recommendations [10], [13], [21]. In three papers [10], [50], [56] Matilda is introduced, a robot with the function of recognizing faces and facial expressions using real-time video in order to help recognize the emotions of its user. Matilda reacts to the emotions displayed by the user through empathetic nods and expressions. However, these are straightforward models of very basic affective dimensions, and the research does not provide any solutions to help improve the user's emotional state in the case of negative emotions. Subagdja and Tan [42] provide a case study using a simulation of older adult care to demonstrate their coordinated persuasion model. Their multiple virtual agents are designed to use persuasive language to motivate older adults to socialize with friends, conduct exercises and provide food recommendations. The virtual agents monitor users and if the need for behavioral change arises, the virtual agents are able to detect this and offer constructive advice. This case study was conducted on virtual test subjects so while their results show that their virtual agents were able to influence virtual users, involving human subjects in the study would be necessary in examining the emotional effects of these virtual agents on older adults. Georgiadis *et al.* [41] present the GrowMeUp system, which provides companionship and offers functionality related to the support of active and independent living, as well as the enhancement of health and psychological wellbeing for older adults. This is done via a robot and dialogue system, with its primary focus on common daily life activities. Although the presented conceptual design is interesting and relevant, as besides understanding behavior, they propose an emotional understanding component for interactions with elderly users to be included in their intelligent dialogue system. Unfortunately, given that the paper reports on a conceptual design, little specific details are provided as to the emotional understanding component and how wellbeing is conceptualized.

E. E-COACHING SYSTEM ARCHITECTURE (RESPONSE TO SECTION II Q4)

In this section, we summarize the results of our analysis regarding the system architectures utilized in previous e-coaching projects. The system implementation is divided into three components: (1) monitoring, (2) processing, and (3) intervention medium.

1) MONITORING

The choice of hardware and software used for monitoring the user's progress with the coaching system is essential to the design of an intervention medium. Here, we distinguish hardware (i.e., physical devices) that records health data automatically and software used to support the user to provide self-reported data. Concerning the hardware, the most commonly reported cases were those of pedometers [1], [2], [9], [28], [32], [36] and [48] or accelerometer-based activity sensors [55], [56] used to track physical activity. Many studies explored the use of robots equipped with a variety of sensors for motion or voice recognition [10], [31], [35], [39], [43], [50], [51], [54], or environmental sensors to detect humidity, gas, and smoke conditions [52]. The authors in [41] did not specify the sensors used by the robot. To be more specific, multiple studies used Microsoft Kinect 3D camera [12], [14], [15], [24], [27], [40] and [45] or other sensors and devices commercially available such as smartphones [6], [17], [22], [26], [33], [34], and [53] and tablets [38], [47]. Other studies utilized devices such as scales and medical devices such as blood-pressure monitors [4], [18], [28], [29] and [46].

In terms of software for self-reporting, the most common examples were mobile/tablet applications [2], [4], [7], [16], [20], [28], [25], [46], [47] and web or PC applications [1], [3], [11], [19], [21], [28], [36], [46], [55], [56]. In some instances, where a robot was used, it was possible to communicate information verbally [10], [40], [41].

2) DATA PROCESSING AND ADAPTATION

In order to establish how data were processed in each study, first, we summarized the technologies used to recognize the user activities or behavior, and second, the technologies used in each project to suggest coaching activities.

TABLE 8. Overview of monitoring hardware and paper classification.

MONITORING HARDWARE	PAPERS
Pedometer/accelerometer-based monitor	1, 2, 9, 28, 32, 36, 48, 55, 56
Robot with environmental sensors	10, 31, 35, 39, 41, 43, 50, 51, 52, 54
Smartphone	6, 17, 22, 26, 33, 34, 53
Bracelet	33, 34
Tablet	38, 47
Sensor (e.g., Kinect or similar)	9, 12, 14, 15, 17, 21, 24, 26, 27, 40, 45
Camera (e.g., webcam)	49
Medical device (e.g., scale, blood-pressure monitor, electronic pillbox)	4, 18, 28, 29, 46

Techniques for recognizing user activities are diverse: a step counter [1]–[3], [11], [18], [32], self-monitoring [36], goal achievement [37], weight measurement and blood pressure with weekly telephone calls by a nurse [4], motion capture [12] and more specifically a camera [27], as well as a Microsoft Kinect camera to assess the movement of the user [35], [42]. In [39], Razer Hydra and a Microsoft Kinect camera were used for activity recognition, whereas in [14], Microsoft Kinect V2 camera was used to recognize and provide real time feedback on body posture of the trainee and the ideal postures that trainees should imitate. In [22], data collected from accelerometer, microphone, and phone usage were elaborated to derive the score for three different dimensions (physical activity, sleep, social activity). Some studies used detection algorithms regarding speech [10], posture [24], gesture and emotion recognition as methods for processing data [6], [31]. In project [17], facial emotion recognition, non-verbal interaction, speech analysis, and the use of semantic representation for human-robot interactions were included in the behavior recognition algorithm. One study used a tablet interface for recognizing the emotional state through pre-defined text [21]. Some papers did not mention at all which technology they used for the recognition of activities [5], [7], [8], [23].

TABLE 9. Overview of software self-report and paper classification.

SOFTWARE FOR SELF-REPORT	PAPERS
Mobile / tablet application	2, 4, 7, 16, 20, 28, 38, 46, 47
Web/PC application	1, 3, 11, 19, 21, 28, 36, 46, 55, 56
Tracking chart	30
Virtual advisor	32, 44
Dialogue system with robot	10, 40, 41

Different ways for the proposal of coaching activities were used: setting goals [1], feedback personalization [6], [31] for negotiating new goals [2], [18], via conversation with an agent and reinforcement learning methods to modify the difficulty level [42]. Data was processed manually by entering measurements and responding to questionnaires [20], or by a human coach [8], [28], [38]. Project INFORMS used predictive analytics, explanatory analytics and visualizations for adapting some coaching activities [33]. In [10], dialogue was personalized according to the user's emotional state and illness status (e.g., dementia), while diet suggestions are described as tailored to each user (diabetic, obese, etc.). Some papers did not mention any type of suggestions for personalizing or adapting the coaching activities [5], [14], [16], [17], [19], [21], [23], [27]. The rest of the papers did not provide a very clear view about data processing technologies and techniques.

3) INTERVENTION MEDIUM

Several studies showed the importance of technology in delivering wellbeing interventions to older users. This section presents the different delivery media: coaching embodiments and coaching systems that are displayed to the user. In other words, we investigate the different design of the virtual coaches, and how they were accepted by the target population. Web or mobile applications were most widely used as an intervention medium for older users [14], [28], [33], [35]–[38], [44]–[49], [53], [55], [56]. For example, a web/mobile or laptop/tablet/PC intervention with a digital health program for older adults with live human coaching was presented to examine older adults' ability to engage in this online program [28]. A digital coach acting as

TABLE 10. Overview of intervention media and paper classification.

INTERVENTION MEDIUM	PAPERS
Web or mobile application	[14, 28, 33, 35, 36, 44, 37, 45, 38, 53, 46, 47, 48, 49, 55, 56]
Conversational agents in software apps	[3, 6, 11, 20, 21,30, 32]
Conversational agents in physical devices	[10, 15, 16, 17, 24, 27, 31, 35, 39, 41, 43, 50, 51, 54]

a personal trainer called Vendla [33] used a smartphone to provide digital wellness services. One paper [34] addressed the young old, describing them as a new, significant market for digital services. It identified key features of early adopters among the young old and showed that wellness services should be digital and can contribute to sustainable wellness routines with the support of digital coaches. Results showed that a majority of the respondents (approximately 73%) use smartphones. Most of the users reported high levels of use and familiarity with smartphone apps and found the apps useful for everyday life functioning. A PC was used in [37] to test whether a self-motivated, complex e-health intervention could improve multiple health-related behaviors that are associated with cognitive aging among working Dutch adults.

Another notable type of intervention medium was found in conversational agents [3], [6], [11], [20], [21], [30], [32]. Conversational agents are shown to be commonly used to interact with older adults for different wellbeing purposes. A relational agent combined with existing computer-based interventions [30] aimed to increase participants' engagement and promote behavior change. All interactions were in real time, allowing participants to ask the Relational Agent (RA) questions and receive immediate answers. Participants viewed the RA as supportive, informative, caring and less overbearing than a human counsellor. The majority of participants viewed the interaction as an important contribution for exercise and sun protection, even though some found it a bit repetitive and overly general. A touchscreen computer was also used as the intervention medium in [5] and [21]. These studies described a similar embodied conversational agent, where an animated computer character simulated face-to-face conversations using a synthesized voice which is synchronized with other non-verbal behaviors such as hand and head gestures, gaze cues, posture shifts and facial expressions. The user could reply to the agent by selecting an answer from a predefined list. Paper [3] worked on a virtual advisor program delivered through a computer, which was a conversational agent named "Carmen". Two papers included in this review discussed this system [11], [32]. These studies aimed to deliver physical advice and support older adults using speech and nonverbal behaviors (e.g., facial cues, hand gestures). Users could interact with it by touching different buttons on the screen. The Embodied Conversational Agents (ECA) interface was shown to be effective, especially with those who had little experience with technology [32]. The virtual coach in [20] was used in a digital environment called eCareCompanion, a tablet-based interface. The interface enabled users to manually enter measurements and answer survey questions. This study investigated the impact of the appearance of this virtual coach on user acceptance in terms of similarity, familiarity and realism. Images of the virtual coach were characterized in order to assess user acceptance in this study. In [6], the authors described a conversational agent integrated in the smartphone.

In addition to virtual representations on screens, conversational agents were often embodied in robots, as shown in [10], [15]–[17], [24], [27], [31], [35], [39], [41], [43], [50], [51], [54]. Matilda [10] was 39 cm tall and weighed 6,5 kg. It came with an intelligent docking station for automatic parking and recharging of its battery. Matilda was a human-like service communication service. Its human attributes included a baby-like facial appearance, face recognition, face registration, face tracking, facial expression gestures, body motion sensors, dance movements, touch sensors, context sensitive emotion recognition, voice vocalization and speech recognition. Expressive faces and conversational agents were also embodied in a robot named Roberta [17]. Moreover, an anthropomorphic robotic torso named Bandit acted as an avatar for supporting the execution of physical exercises [24]. An avatar robot was also proposed in [15] to support the execution of physical exercises while playing against another robot. In [27], a social assistive robot, realized through a touchscreen tablet mounted on robotic wheels, provided audio and visual instructions for the execution of flexibility, strength, and balance exercises. A conversational robot for encouraging daily healthcare was also proposed in [16]. ROBIN [31] was a telepresence robot to better reflect the needs of older users and thus foster social inclusion. It used gesture and voice recognition and was considered to be usable and to provide pleasant interactions by most initial users. The authors reported that open-minded users tended to have a more positive experience interacting with it. The GrowMeUp project [41] aimed to provide an innovative and affordable service robotic system to support older people in carrying out daily activities in their home environment by considering their capability degradations throughout the aging process. It was a dialogue system, in which the robot's knowledge can increase using cloud computing technologies and machine learning algorithms. In [54], virtual coaches took the form of robots for learning assisted activity (RAA). They were supposed to facilitate learning and improve cognitive functioning. The results of this study showed that the subjects' moods improved as well as the communication between them, other residents, and the facility staff. In addition, there was a positive change on depressive feelings. Paper [35] proposed a Preventive Care system with learning Communication robots (PrevCareCom), aiming to provide a preventive care approach to counteract falls, wherein the older user could engage in exercise over the long term without getting bored by communicating with robots through match-up games. The experiments showed that the rival robot could acquire behavior, allowing it to be an appropriate competitor to the avatar robot, or the user. The results of experiments conducted with older adult participants in health and welfare facilities also showed that the participants' interest in the system and sense of familiarity with the robots were encouraged by actually playing the game and interacting with the robots rather than by watching a demonstration. Other works studied the development of a Robotic coach Architecture for Multi-User (RAMU), which is a human robot [39]. Jawbone UP was also adopted as a delivery medium in [29].

To sum up, there are many examples of ICT solutions being used with older adults in order to help them to maintain or improve their wellbeing. The majority of adults in later life tend to accept using these technologies to achieve a healthier lifestyle. However, many studies have shown that the use of technologies is still complex. In particular, conversational agent capabilities are still limited and remain an open field for research.

F. STUDY RESULTS

As shown in Table 1, only six studies included a randomized trial. We report in this section the main results obtained in these studies. Paper [2] showed that the group that used the conversational agent significantly increased the number of steps per day after a 2-month intervention. In contrast, no effect emerged for the effectiveness of the agent to reduce loneliness and increase user satisfaction with life. The acceptance and usability of the conversational agent were overall positive. The results after a 12-month follow-up, presented in [3], showed that there were no significant long-term effects. The authors also showed that the intervention was more effective in individuals with higher health literacy. In [11], similar results were presented. At the end of the 4-month test, there was a significant increase in walking activity for the intervention group. However, as in the previously reported case, even if the system was generally well accepted and considered easy to use, in the 20-week follow-up, there was a gradual drop-off of system use, indicating possible limits of the system's usability and related effectiveness maintenance. In [55], [56], the authors used an internet-based intervention (3 months) to foster physical activity in a group of inactive older adults without diabetes. In [55], they reported a significant improvement in terms of quality of life. In particular, 42% of the participants successfully reached their physical activity target and showed a significant improvement in terms of emotional and mental health and health change. In [56], they reported an increase of 11 minutes per day in terms of moderate-to-vigorous activity (versus 0 minutes in the control group). They also showed a significant weight, waist circumference, and fat mass decrease. In addition, the insulin and HbA1c levels decreased significantly more compared with the control group. In [48], the users affected by Parkinson's Disease had to interact 5 minutes per day during a month with a virtual coach encouraging walking activity. The participants had an average satisfaction score of 5.6 out of 7. Both the 6-minute walk test and speed significantly increased compared to the baseline. To sum up the results of the six randomized trials, there is initial indication of moderate to high degrees of acceptance and usability, and initial findings of positive interventions effects on target outcome variables. The few current findings based on randomized trials in the area of health-related e-coaching for healthy older adults do indicate some caution in terms of longer-term maintenance of the observed intervention gains. Concerning the preliminary usability investigations that we reviewed, it is worth to highlight that not all the studies involved appropriate control groups to fully evaluate the specific effectiveness of the proposed coaching system. The exercise systems based on Kinect for body tracking presented in [12], [14], [31], [35], [43], [45] received a good appreciation from the users who tested it and a good level of engagement and motivation. However, sometimes finding sufficient space at the participants' homes was an issue [45]. In [13], social engagement increased slightly over an 8-month pilot study testing a system designed to promote older adults' social interactions. The authors reported that the feedback display showing the network of social contacts of the user as a "heliocentric representation" (i.e., the user was at the center of the network) facilitated motivation to use the system. Different kinds and forms of robots were used in many pilot studies [31], [35], [39], [43], [54]. Most of them aimed to facilitate a feeling of familiarity and affection towards the robot. In a one-week pilot study with 14 older adults involving a conversational agent for reducing loneliness, the system was accepted by the user group and exercise promotion and anecdotal stories reduced perceived loneliness (participants reported to feel a sense of companionship with the conversational agent; [21]). Two participants introduced the agent into their social network (friends or family) by discussing about the agent's personality or other situations. The proactive approach (i.e., the system prompts the user for interaction) was more successful in reducing loneliness than the passive approach (i.e., the user needed to initiate the conversation with the agent). In [26], a 9-week intervention for promoting socialization showed that all participants improved their level of socialization and continued to see a benefit in the maintenance phase of coaching (after the nine weeks) from using Skype to communicate with remote family members and friends.

V. DISCUSSION

The aim of this systematic review is to answer four research questions, defined in Section II. We discuss the findings related to each question, analyze the results and emphasize the gap (if found) and finally, we define some new approaches to some research questions.

A. Q1. WHICH ARE THE DIFFERENT DEFINITIONS FOR "COACH" AND "COMPANION"?

In our sample of articles, we found only two formal definitions of e-coach and no definition for companion. Nevertheless, in Section IV.B we identified the characteristics that e-coaches and companions for older adults' wellbeing improvement should present according to the analyzed studies. Based on these characteristics, we elaborated the following definition: "An e-coach is a system that collects and processes a user's data in order to provide a personalized intervention able to support and motivate the user to reach her goal. The virtual coach is able to do so through a set of behavior change techniques that guide the user to develop internal and external structures that help to achieve success and to increase her potential by expanding the personal sense of what is possible. The virtual coach is further able to build a sense of companionship for the user. It is a good, cuddly and loving entity, providing a warm and pleasant sense of companionship and able to dialogue in a kind and sweet way, while at the same time supporting the user to stay on track of her personal goals, in order to act like a close friend'' [71].

This definition, as well as our findings from literature, confirm and corroborate the set of features proposed by B.A Kamphorst for a generic e-coaching system [74]:

- Social ability: The coach should be able to engage in a conversation with the user.
- Credibility: The system has to be perceived as having expertise and being trustworthy.
- Context-awareness: The system needs to be aware of user context to propose ideas and actions that are relevant for the user.
- Learning abilities: The system needs the ability to ask questions, give feedback, and offer advice that is tailored to the individual user, building up and maintaining a personalized user model.
- Data gathering: The system will need to interface with different types of data streams (e.g., direct user input, but potentially also measurements of physical activities, mood self-reports, sleeping patterns), to provide individually tailored coaching.
- Proactivity: The system should initiate interactions with the aim of stimulating action.
- Reflection: The system should initiate interactions in a proactive manner, depending on user's sensed or predicted behavior.
- BCM integration: The system needs to know how a behavior change trajectory looks like in order to provide successful coaching.
- Planning support: In order to support users in setting themselves up for behavior change success, the system should guide the user through the intention formation with appropriate planning strategies.

To resume our findings and our definition, we conclude that an e-coach should have three basic roles: being a coach, being a friend and, finally, being a companion. Each role should have a particular goal in the users' pathway towards wellbeing [72].

B. Q2. WHICH BEHAVIOR CHANGE MODELS (BCMs) AND BEHAVIOR CHANGE TECHNIQUES (BCTs) WERE USED?

Although only in 18 of the 56 papers grounded their e-coach on a theoretical model of behavior change; there is evidence of greater effectiveness of theory-based behavior change interventions over those that are not grounded on theory [36]. The most common model used was the Transtheoretical Model; yet, there is no evidence on which is the most effective behavior change model. The Health Action Process Approach (HAPA) [63] is one of the most recent models in the health-behavior change literature (it was indeed adopted only in one of the 56 papers reviewed here); however, it currently seems the most promising one. Indeed, the HAPA model represents an integration between continuum and stage models of behavior change and additionally addresses the intention-behavior gap that other models often neglect. Its advantage over the earlier models is that it focuses on two distinct phases (i.e., the motivational phase and volitional phase) and on phase-specific psychological factors explaining or underlying behavior change (or its failure) in each phase. It allows a closer examination and understanding of those variables that underlie intention formation and it addresses the intention-behavior gap by including variables (mainly from the self-regulation domain) that mediate the relation between intentions and the target behavior. It is thus more comprehensive than other models, which often successfully predict intention itself, but then consider intentions to be the proximal predictor of behavior, therefore ignoring the often-found intention-behavior gap.

The most frequent BCTs applied in the randomized trials were the personalization of goals and content, followed by using validity-tested devices, and combining self-tracking and e-coaching. These BCT methods were found to positively affect health outcomes and usability in these studies.

Thus, it is crucial to implement a variety of BCTs to sustain the motivation.

Based on this systematic review, the eight BCTs that we already discussed are important for building future intervention systems, including general educational information, information of health consequences, prompting intention formation, instructions, specific goal setting and reviews on behavioral goals with detailed feedback on health behaviors [70].

C. Q3. HOW ARE DIFFERENT DOMAINS TACKLED IN PREVIOUS STUDIES?

Although a multi-domain approach (meaning two or more domains) was adopted in half of the papers, only four of them had a holistic approach and tackled four or more domains.

Similar conclusions can be drawn for each domain of wellbeing.

Indeed, in the physical activity domain, the vast majority of the virtual coaching systems included in our review were not implemented in a fully holistic approach, i.e., considering all the subdomains (aerobic/endurance, strength/resistance, flexibility, balance) that are fundamental components of the main domain. In order to be effective, an e-coach should propose activities and plans including all the subdomains as suggested by the WHO [67]. Furthermore, its effectiveness can be, in our opinion, even stronger if a personalization of the coaching plans, considering the actual status of the subjects, is proposed. Another limitation of the current coaching systems is the lack of compliance to the international guidelines of physical activity for older adults (aged 65 and above) [68]. For example, the proposed coaching plans should be implemented considering that at least 150 minutes of moderate-intensity or at least 75 minutes of vigorous-intensity aerobic physical activity should be performed throughout the week. Furthermore, muscle strengthening activities and exercises to enhance balance and prevent falls should also be included.

In the nutritional domain, the analyzed studies concentrated mostly on healthy dietary habits, while only one proposed a hypocaloric diet. It is worth to highlight that no e-coaching system tackled the problems related to malnutrition and sarcopenia with hypercaloric and hyperproteic diets. Because of their important impact in aging, these subdomains should be proposed in future e-coaching systems.

In the cognitive domain, e-coaching systems are not (yet) at the forefront of cognitive training and intervention research, which in itself has a decades-long history in aging research overall. Very few of the studies identified in the present review focused on the cognitive domain at all. Given that the most important challenge in cognitive training interventions to date is the lack of strong transfer effects to untrained abilities, it remains to be seen which role e-coaching systems can really play in fostering stronger findings in this regard. It seems most plausible that e-coaching systems can be used to foster a more general sense of staying cognitively engaged in a number of ways, i.e., both through the suggestion and presentation of structured cognitive training, but also in the sense of more general BCT messages that encourage the uptake and learning of new skills.

The social domain was a target in one third of the identified studies, and mainly focused on direct or remote social interactions, befriending, and social connectedness overall. They thus resemble in focus general social interventions, which tend to primarily aim at the reduction of loneliness via the creation of opportunities for social contacts. E-coaching systems should be more carefully examined as possibly useful tools to enhance social contacts and thus feelings of social embeddedness in subgroups of (lonely) older adults who, for a number of reasons, cannot directly engage in-person contacts (e.g., adult children living too far away, living in rural areas, etc.). The initial evidence is sufficiently promising in the social area for e-coaching systems to remain a focus of health and wellbeing research in the e-coaching for later life area.

In the emotional domain, we found that given the complexity of human emotions and related aspects of mental wellbeing, it would seem to be a missed opportunity not to attempt to integrate a broader and more complete set of emotion sensing models and tools. Researchers need to be increasingly aware that older adults need personalized support that is not only physical, nutritional and social, but incorporates the emotional domain as well. There is still a clear gap in the research on automated understanding of emotions in e-coaching, and, as importantly, in the necessary processing of the detected information, particularly in the case of negative emotions, to provide an adequate reaction by the e-coach (possibly via a conversational interface). The need to utilize the emotional cues from the user and process the possible causes as well as provide possible solutions is distinctly absent in all e-coaching systems we have come across and reviewed in this literature review.

Choosing a multidomain approach including all the interventions that are critical for aging and that were often neglected in previous literature is a missing area which interest us to fulfill this gap. Having a system that can also choose to train the muscle strength and follow a hyperproteic or hypercaloric diet depending on user's preference and needs is what motivate us to work on a multidomain system that provides e-coaching in physical activity, nutrition, cognitive, social and emotional domain. We also believe that the emotional status of the user is still complex and an appropriate intervention respecting mental wellbeing should always be fully considerate.

D. Q4. HOW ARE DIFFERENT SYSTEMS IMPLEMENTED IN TERMS OF MONITORING, PROCESSING AND DELIVERING THE INTERVENTION?

Among the e-coaching architectures analyzed in this review, few adopted multiple monitoring systems to collect data about users [1], [10], [33], [36], [41]. Monitoring systems were constituted by a mix of pedometer/accelerometer and a Web app [1], [36], a dialogue system in a robot with environmental sensors [10], [41] or a mix of a smartphone and a bracelet [33]. The latest studies issued from 2016 until 2019 have used a pedometer [32]–[34], [36], [38], [55] or environmental sensors such as a Microsoft Kinect camera for recognizing posture and movement [27], [35]. Three of these studies combined automated monitoring with self-reported life-logging through web or smartphone [33], [34], [36]. Combining automatic data collection and user self-reports is a key approach for collecting reliable data belonging to different wellbeing domains. Indeed, while physical activity can be easily tracked through physical and environmental sensors, the nutritional domain can still be tricky with purely automated monitoring. In contrast, the self-perception of social and emotional domain may differ from what the system would be able to measure.

Few best practices could be found in literature for data processing and e-coaching adaptation. The open challenge in this field is providing reliable coaching based on expert recommendations and dynamically adapting these recommendations to the user preferences and needs. While technological advances may suggest that machine learning can conveniently provide an automatic adaptation and personalization of a coaching intervention [75], the risk of algorithmic bias introduced by machine learning [76] may actually discourage the use of these systems. Recommender systems based on rules designed by experts may still serve a better job. We believe in the necessity of building in any healthcare virtual coach system a Decision Support System [77] that can analyze the data collected through automated monitoring or self-reporting, and also based on both user preferences and experts' recommendations, in order to provide personalized coaching plans for each of the different domains tackled by the system.

In terms of intervention delivery, conversational agents have been mainly proposed in the recent studies issued from 2016 [17], [20], [27], [30]–[32], [35], [39], [41]. In particular, we have four studies that used conversational agents embedded in software apps and six studies that used physically embodied conversational agents (e.g., in robots). Since language is the primary modality used to build human relationships [73], we believe that, with the increasing capabilities of voice services and natural language understanding, conversational agents are becoming particularly interesting as e-coaching intervention medium for older adults. Indeed, one of the key characteristics of an e-coach is the sense of companionship that it should create. Multimodal interfaces can further enhance the capabilities of a conversational e-coach. For instance, a conversational agent embedded in a software app may be used while the older adult is on the move, while a physically embodied conversational agent can be used at home in order to build greater empathy and bonding with the user [69]. Moreover, some BCT implementations (e.g., calendar scheduling for action planning, charts for self-reflection) may be easier to use on smartphone or web interfaces: an e-coach can then benefit from the use of different interfaces depending on the type of information that should be delivered to or requested by the user.

VI. CONCLUSION

We conducted a systematic review to analyze previous work carried out in the area of virtual coaches for improving the wellbeing of older adults (65 years old or above). Our aim was to find procedures that specifically targeted healthy older adults and implemented behavioral change techniques suggested by health professionals in different domains: physical, nutritional, cognitive, social and emotional. This systematic review showed a developing agreement in what was considered a virtual coach for older adults' wellness. Few studies examined the long-term use of these systems, emphasizing the need to better understand the best technological solutions with related interventions to be actually accepted and adopted by older people in a sustainable manner. Our analysis suggested that virtual coaches for older adults should address the different wellbeing domains with a more holistic approach, without stopping to typical interventions for improving the cardiorespiratory fitness or healthy dietary habits. Since many behaviors change models had difficulties in bridging the gap between intention and actual behavior change, we individuated the HAPA model as an appropriate framework for grounding an e-coaching intervention. On the technical side, we saw that monitoring the user wellbeing in different domains is inherently complex, and automated sensing should be complemented with self-reporting. To this purpose, conversational agents should not only make an e-coaching intervention more convenient and user-friendly, but also, they should help building empathy and increasing the user's trust in the e-coach.

NESTORE Coach is a project funded by the European Commission for promoting older adults' wellbeing. In this project, we adopted the virtual coach definition proposed in this paper (Section V). We decided to adopt the HAPA model in order to overcome the difficulties often encountered in actual behavior change. In order to familiarize the users with the behavior change process, we introduced the word "pathway" to represent the journey that each user should regularly go through, introducing healthy activities and behaviors into their daily routines [70].

Since we were interested in a multi-domain intervention, we identified different sub-domains for each domain (typically associated to the intervention types described in Section III.D) that users could choose to build a personalized pathway to reach their goals [70]. Thus, the key variables able to affect intention and behavior change according to the HAPA model (e.g., motivational self-efficacy, action planning, etc.) were mapped to different BCTs implementations for each phase of the model. We chose the HAPA model in order to overcome the difficulties often encountered in actual behavior change. This e-coach combined automated monitoring (wearable sensor, social beacons, cognitive games and text semantic analysis for sentiment detection) with self-reporting questionnaires for the cognitive, social and emotional wellbeing. In the nutritional domain, food self-reporting is complemented with deep learning analysis of user's dish photos in order to estimate their nutritional content. All these interventions are delivered through the best user interfaces we found in this analysis, i.e., a conversational agent (textual and physically embodied) and a mobile application [69].

The research on e-coaching systems improving older adults' wellbeing is becoming a major topic in computer science and the results presented in the studies here analyzed provide important lessons and new directions for future works. However, this systematic review highlighted also the need for more rigorous evaluation processes and thus it is important, as last message of this paper, to encourage researchers to opt for study designs such as randomized control trials that can help to create comparable and reliable results for the whole scientific community.

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