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RESEARCH ARTICLE

Designing for social relatedness between stroke survivors and eHealth: 'Edo' an embodied coach for stroke rehabilitation in the home context

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ABSTRACT

eHealth solutions at home are gaining interest and relevance in healthcare; however, they face challenges in sustaining motivation for therapy due to difficulties in creating meaningful connections between technology and people receiving care. In this article, we explore how embodied agents in eHealth interventions could be designed to establish a motivating relationship with people in the context of home-based stroke rehabilitation. We studied this potential by referring to the need for social relatedness in Self-Determination-Theory (SDT) and how this translates to the design of embodied agents' characters, the collaborations they afford and the partnerships they establish over time. In co-creative ideation sessions with stroke survivors, this potential was explored, resulting in an interactive prototype of 'Edo the Coach', i.e. an embodied agent for home-based upper extremity stroke rehabilitation that was evaluated by stroke survivors in their home contexts. Based on the insights gained, we reflect on the potential of using SDT for designing embodied agents that foster motivational relationships between patient and agent as an answer to the growing demand for eHealth-supported self-care within an increasingly digitized healthcare context.

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eHealth; motivation; embodied agents; human-agent interaction; stroke; rehabilitation at home

Introduction

Healthcare, particularly rehabilitation, is shifting from the clinic and hospital to the home environment (Langhorne and Baylan 2017; Camicia et al. 2016). In stroke rehabilitation, often only a small part of the trajectory happens

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inside the clinic, and stroke survivors must continue exercising at home (Alankus et al. 2010). Early supported discharge post-stroke is affordable and may have the advantages of independence in daily life activities and reducing disability (Langhorne and Baylan 2017). One of the ways to facilitate early supported discharge is the use of eHealth (Langhorne and Baylan 2017), defined as 'the use of information and communications technology in support of health and health-related fields' (World Health Organization 2016). However, research shows that stroke survivors understandably have difficulty staying motivated throughout the often lengthy rehabilitation period (Alankus et al. 2010; Chen et al. 2019). One of the causes for this may be the challenge in creating a meaningful relationship with the home-based eHealth solution compared to a conventional therapist-patient relationship in a clinic (Jackson et al. 2012; Hall et al. 2010; Peiris, Taylor, and Shields 2012).

Embodied agents, i.e. physical objects that embed computational technology with the ability to interact with its users proactively, are gaining interest in eHealth design (ter Stal et al. 2020; Hurmuz et al. 2022). Yet, to the best of our knowledge, their potential to establish motivational relationships with their users during the process of rehabilitation has received less attention. Taking the context of remote stroke rehabilitation, this study investigates the potential of embodied agents to establish a motivational relationship with their users by designing the agents to answer the users' need for social relatedness as described in the Self-Determination-Theory (SDT) (Ryan and Deci 2000). We applied a Research-through-Design methodology (Stappers and Giaccardi 2017) to design three concepts and one interactive prototype that were evaluated with stroke survivors to learn about how social relatedness in STD can be productive for designing motivating eHealth solutions.

We will first introduce SDT and conceptualize how it can be applied into the design of embodied agents. In the method section, we then address the two phases of the case study: Concept phase and Prototype phase. The Concept phase includes a participatory session where stroke survivors experienced the interaction with three concepts of embodied agents in the form of rehabilitation coaches (i.e., concept coaches). In the Prototype phase, we show how the results of the Concept phase informed the design of an interactive prototype, which was evaluated by stroke survivors on the type of relationships it stimulated. Finally, the article concludes with a reflection on the study's implications on designing motivational human-agent interactions in eHealth-supported remote care.

Theoretical background: the SDT need for social relatedness as a ground for design concepts of motivating human-agent relationships

According to the Self-Determination Theory (Ryan and Deci 2000), humans have an intrinsic need for autonomy, competence and social relatedness. The

need for social relatedness has our particular interest given the reduction of human patient-doctor contact in remote care and the technological opportunity offered by eHealth technologies that are becoming increasingly more intelligent and capable to interact with users for longer periods of time and consequently establish relationships.

The need for social relatedness encompasses experiencing a *sense of belonging, attachment, closeness, and intimacy* with others (Reis and Patrick 1996; Mikulincer and Shaver 2016; Baumeister and Leary 1995): it is a basic need that explains people's behaviour to relate to other humans and socially engage (Deci and Ryan 2014). This study investigates if social relatedness can serve as a psychological need to design motivational relationships with embodied agents in the context of at-home rehabilitation.

We draw on the work by Rozendaal, Boon, and Kaptelinin (2019) to conceptualize how SDT-based social relatedness can be applied to the design of embodied agents (see Figure 1). In line with their findings we refer to three basic interactive agent design features, namely: (1) *character,* the agents' embodiment that is designed by its material composition, shape, behaviour, associations it elicits, and personalities it expresses, (2) *collaboration* as the mutual interaction and working together of humans with the agent, and (3) *partnership* as the way in which the agent can adapt over time (across multiple interaction episodes) to the developing skills and needs of the person.

We have preliminary indications of how motivational relationships of a person with embodied agents can be created by relating the proposed design features of the agent to the person's need for social relatedness. The work conducted by D'Olivo et al. (2020) showed how the character of an agent can be experienced as friendly and tactful. Since both experiences are required to sustain healthy relationships between humans (Baumeister and Leary 1995) such a relationship might as well occur between agents and humans. With regard to human-agent collaboration, it is possible to elicit feelings of shared interest and trust (Cila 2022) which (a) are needed for

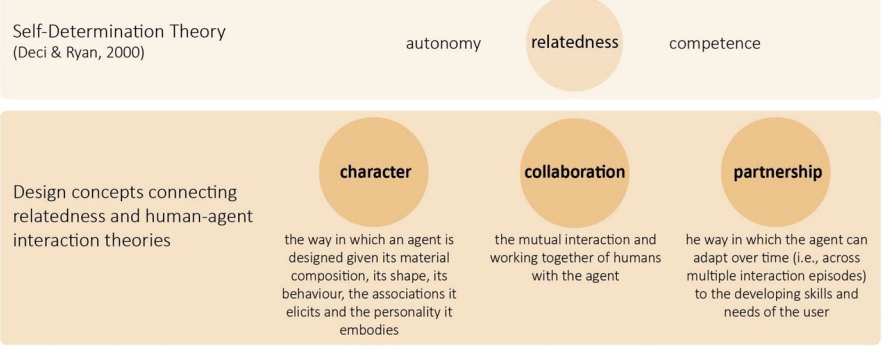

Figure 1. Theoretical model combining Self-Determination Theory with theories of Human-Agent Interaction.

highly valued human-human relationships (Deci and Ryan 2014), (b) are associated with maintaining long-term relationship interest (Kluwer et al. 2020), and (c) foster the development of positive self-esteem (Baumeister, Heatherton, and Tice 1993). Since basic qualities of a human-human social relationships can be elicited by the design of agents, it might be possible for agents to answer the human need for social relatedness and thus motivate humans for human-technology interactions (Fox and Gambino 2021) and support humans in remote-care contexts.

Method

We have used a Research-through-Design approach (Stappers and Giaccardi 2017) to explore to what extent embodied agents can be designed to establish motivating relationships through social relatedness, consisting of design and research activities structured in two iterative phases referred to as the 'Concept' and 'Prototype' phase (Figure 2). With the Concept phase, we aimed to understand what type of relationship is perceived as motivational by stroke survivors and which type of characters, collaborations, and partnerships were deemed desirable to support this. The Prototype phase involved the design of an interactive prototype, 'Edo the Coach', to evaluate the extent to which the design is recognized and appreciated by patients for enabling motivating relationships.

The study is part of the ArmCoach4Stroke (AC4S) project, a collaboration between Delft University of Technology (Delft, NL), Erasmus Medical Centre (Rotterdam, NL), Rijndam Rehabilitation Centre (Rotterdam, NL), University of Twente (Enschede, NL), Amsterdam UMC (Amsterdam, NL), 2M Engineering (Valkenswaard, NL) and Umaco (Groningen, NL). The Human Research Ethics Committee of the Delft University of Technology (Netherlands) and the Medical Ethical Committee of the Rotterdam Erasmus Medical Centre (Netherlands) approved the study (protocol number MEC-2021-0862).

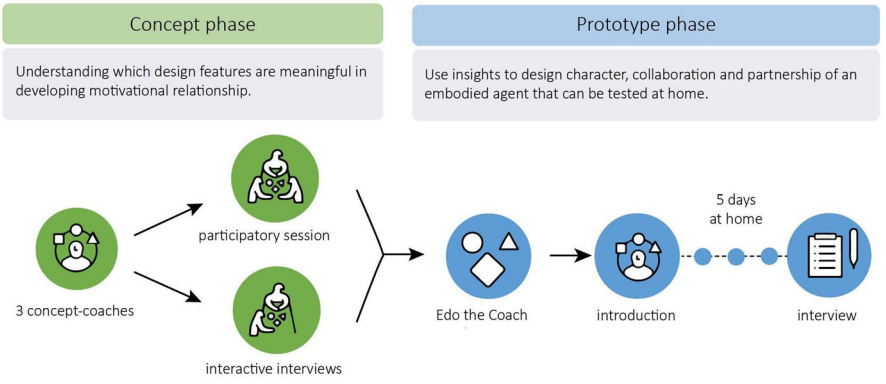

Figure 2. Study design.

Procedure

In the Concept phase, three concept coaches were designed to learn to what extent their embodiment as related to character, collaboration and partnership are creating a social relatedness that motivates patients for rehabilitation at home. The concept coaches were evaluated with five stroke survivors in the chronic stage[1] in a 2.5-h participatory session and six stroke survivors in the subacute stage[2] during individual interactive interviews of 60 min each. All participants provided informed consent and opinions on the cases under study (see Appendix 3(A)). Three researchers conducted the session following a script (see Appendix 1) listing a series of activities to trigger conversations among participants. Concept coaches in the form of props were presented (the complete description of the coaches and their components are presented in the *Concept Phase – subsection: Design*). One of the participants was asked to wear the coach components while one of the researchers enacted the coach's behaviour. After the enactment, the whole group reflected on motivational aspects and possible improvements.

In the Prototype phase, Edo the Coach was tested by ten stroke survivors at home for 5 days (the complete description of Edo the Coach is presented in the *Prototype Phase—subsection: Design*). On Monday, two researchers introduced Edo to the patients. On Tuesday, participants got acquainted with Edo. Wednesday and Thursday were training days on which participants performed exercises with Edo and filled in a paper logbook to evaluate the session. On Friday, the researchers returned to the participant's home to conduct a semi-structured interview of 60 min. Questions were aimed at capturing the experience of Edo's character as an embodied agent, ways in which Edo could foster training exercises within the home context, and how Edo could be sensitive and adapt to a person's developing needs and skills. See Appendix 2 for the interview script.

Participants

In both phases of the study, therapists from the Rehabilitation Centre facilitated participant recruitment, and consent was obtained from each participant involved. We included adult (> 18 years) unilateral ischaemic or haemorrhagic stroke survivors in the subacute and chronic stage[3] with motor hand/arm impairments as a result of stroke, still able to perform over 30 degrees shoulder anteflexion, show voluntary finger extension, carry out activities of daily life, and able to provide informed consent. All participants were discharged home from a rehabilitation centre. Five participants were enrolled to try out the concept coaches in the Concept phase and ten participants tried out the prototype in the Prototype phase. Participant details are presented in Appendix 3.

Data collection and analysis

Sessions and interviews across both research phases were recorded through audio, video and photos, transcribed verbatim, anonymised and translated. The translation from Dutch to English was performed by (DS) and (OT), both native Dutch speakers also proficient in English. The translators were involved in analysing the materials to ensure Dutch nuances were included. The materials were analysed by means of an inductive analysis following three steps: (i) coding quotes describing design features; (ii) clustering codes in broader topics and the topics in themes; (iii) and then reducing the number of quotes (Saldaña, 2014). Three researchers were involved in active coding and analysis. In both the Concept and Prototype phase, an additional third (AJL) and fourth researcher (AG) validated the analysis afterwards to reduce possible bias.

Concept phase

The Concept phase aimed at gaining an initial understanding of design features which can be beneficial to create social relatedness between user and embodied agents, referred to as 'concept coaches'. The concept coaches enabled participants to reflect on the design features they would value in the context of home-based rehabilitation after a stroke.

Design

The concept coaches were designed based on the insights of earlier conducted research. This included onsite observations of the interaction between stroke survivors and therapists, informal interviews with therapists and stroke survivors and a literature review on current interventions for upper extremity stroke rehabilitation (Pollock et al., 2014; Chamberlain and Xiao 2020; Alankus et al. 2010; Chen et al. 2019). Based on these insights, three concept coaches were developed (see Figure 3). The technical components involved wearable sensors, a screen, and supportive physical objects. These components have been chosen based on technical requirements imposed by the overall project this work was part of.

The 'Bootcamp coach' was designed to create *social relatedness* by acting as a strict and assertive coach. Specific character-collaboration-partnership features were integrated to obtain that. To embody the assertive and energetic *character* of Coach Bootcamp, we turned the technical components into training devices with colour accents like gym items used during a physiotherapy session (e.g., weights, elastics, balls, pillows, cups, etc.). The *collaboration* style resembles interacting with a physiotherapist who gives strict instructions, observes progress, and uses encouraging words, when building up a *partnership* over time.

Figure 3. Concept-coaches.

The 'Magic Training Objects' were designed to create *social relatedness* by acting as a system of digital assistants, and specific character-collaboration-partnership features were integrated to obtain that. To embody the futuristic and modern *character* of the Magic Training Objects, we referred to devices and wearables such as iPhone, iWatch, FitBit, etc. The *collaboration* style and *partnership* resemble the interaction with this technology that provides instructions to the users via different sensory inputs.

The 'Arm Companion' was designed to create *social relatedness* by acting as a friendly and caring coach, and specific character-collaboration-partnership features were integrated to obtain that. To embody the friendly *character* of Arm Companion, we turned the components into soft and warm wearables with foam and fabric and we included a smiley character in the tablet interface. The *collaboration* style and *partnership* resemble the interaction with a close friend or a family member who behaves in a supportive way by taking the time to listen and providing emotional support.

Evaluation

The following paragraphs summarize the participant's opinions on the concept coaches and the creation of social relatedness over four main themes. Supporting quotes used to structure the results are included in Table 1.

A coach that is demanding and friendly at the same time

Coach Bootcamp and Arm Companion were preferred over the Magic Training Objects. Coach Bootcamp was appreciated because it strictly demanded action while Arm Companion was appreciated due to its friendliness and

Table 1. Opinions of stroke survivors on concept-coaches.

Theme	Interpretation	Quote
Demanding and friendly	Assertive	'I would choose bootcamp because [it] is demanding.' - P2
	Friendly	'That concept of a buddy who stimulates […]charms me.' - P5
	Change according to moment of interaction	'To me you have to get the coach [=Coach Bootcamp] to start the training […]. Arm Companion is your friend […] to help you to recollect something that you don't remember.' - PF3
	Distant	' Those magical training objects, I found them distant' - P4
Communicate in a simple and clear way	Clarity	'It has to be very clear because you have people who can't read and understand very well.' - P2
	Simplicity	'[Arm Companion] was more to the point, but still messy. To the point I want.' - PM1
	Video instructions	' A video is sufficient […] for people with aphasia.' - PF2
	Stimulate senses	'As a basic Coach Bootcamp […] with the sounds and the colours from the Magical Training Objects […]. To combine the ways to perceive' - P2
Fit the patient's routine	Fit existing structure	'Everything has to fit into structure' - P3
	Training reminder	'Make it like a watch where you can see […] 'Oh, I have therapy".' - PF1
	Break reminder	' I think [a break reminder] is nice. I'm not one to take breaks easily.' - PF3
Empathise, motivate and evaluate	Empathise with patient's needs	'If it doesn't work, they [=therapists] will say 'we will stop because you are not going to force anything. […] do what you can'- PM3
	Encourage with words	'I'd get farther if it says: "you're almost there or good job or 2 more exercises."' - P4
	Check quality of movement	'I check if I've done well technically, regardless of performance. […]. If I'm sloppy, I can achieve more but I'm ruining my body. ' - P2
	Reach improvements	'Having achieved something is more useful than a certificate. […]. It is for your own body to let it function normally again.' - PM3

analogy to someone close and for giving guidance. For the participants, the ideal coach would embody these two aspects as they help in creating a sense of connection with the agent. Magic Training Objects was appreciated less compared to the other two concept coaches because of the lack of specificity in the feedback it provided.

A coach that communicates in a simple and clear way

Because of the cognitive limitations caused by stroke, such as difficulty in comprehension and getting easily overwhelmed, participants addressed the need for a clear and straightforward interaction that helps in understanding the purpose of what is requested to do. It should further not be experienced as childish, as this would generate awkwardness and the perception of not being taken seriously by the coach. Participants suggested a combination of video and light to explain the exercises in a clear way and to create an immersive sensorial experience. For example, coaches Bootcamp and Arm Companion relied on video, while Magic Training Objects relied on the tangible objects giving light.

A coach capable of fitting within a person's daily routine

To establish a relationship with the coaches, the repeating exercises provided by them should fit into people's everyday routines, which, as a participant mentioned, may already be quite structured and demanding. They further mentioned liking these coaches notifying them about when to start an exercise session and providing them with reminders to take little breaks in between doing the exercises.

A coach capable of empathizing, motivating, and evaluating

Participants expressed the need for a coach capable of being empathic, which they described as the coach being able to listen to their needs as a therapist would and responding by using encouraging and motivating words. Moreover, encouragement should be provided together with feedback on performance. Participants consider feedback essential for trusting that the coach monitors whether movements are performed safely, and improvements are reached.

Participants' reflections on their experience using the three coaches during the enactments highlight aspects of the designs they deemed important for building motivational relationships with embodied agents in rehabilitation therapy through social relatedness. Generally, participants expressed the need to interact with coaches that appear empathic without being too childish, and capable to balance the necessity to deliver strict rules (i.e., the embodiment of Bootcamp Coach) while being gentle at the same time (i.e., the tone of voice in the interface of Arm Companion).

Participants also indicated that collaboration with these coaches depends on how clearly the coach explains its purpose and provides guidance and feedback while doing the exercises (i.e., the rules to follow indicated by Bootcamp Coach and the real-time light feedback of Magic Training Objects). Participants felt more connected with physically embodied coaches rather than virtual representations on a screen, i.e., they liked coaches that used multiple sensory modalities in communication (the use of haptics, light, sound, etc.) (i.e., the whistle sound of Coach Bootcamp to start the training, the light feedback embedded in physical objects of Magic Training Objects, the explanations via voice of Arm Companion). Lastly, participants addressed how they envisaged how the partnership with these coaches could develop by imagining an evolution of their behaviour. They stressed the need for a coach capable of instilling a sense of safety, which could be generated by reactive behaviour, such as immediate feedback on performance after each exercise interaction. In conclusion, for a motivational relationship participants expressed the importance of elements such as tone of voice, clarity in communication, physical presence, and safety. These elements hint at social relatedness, which we thus can conclude as being relevant for designing motivating relationships with embodied agents.

Prototype phase

The insights of the Concept phase were used in the Prototype phase to design 'Edo' the coach and deepen our learning about social relatedness as a means to motivate people. The tone of voice was used as a design element to foster a sense of intimacy between the users and Edo. Clarity in communication was used to inspire a sense of attachment between the user and Edo, and lastly the elements of physical presence and safety were used to nurture a sense of belonging.

Design

Edo was designed as a system based on three elements: a *screen* on which instructions were given, one object that served as a *practise tool* and communicated via light feedback at the conclusion of the exercises and a *disc-shaped component* that communicated via light and sound with the participants the start and the conclusion of a training during the day (Figure 4). With Edo, the wearable sensors were excluded, and the cylinder and the cube objects were combined into a single practise tool. Edo embodied specific features related to character, collaboration, and partnership to foster social relatedness with the participants (see Figure 5). We aimed at embedding a calm *character* in Edo capable of instilling a *sense of intimacy* while communicating to the user and to do so we used its screen with a digital interface based on gentle

Figure 4. Edo the Coach.

colours, rounded shapes and minimalistic drawings. We aimed at embedding a style of *collaboration* based on continuous feedback to instil a *sense of attachment* and continuous interest of Edo in the progress achieved by the participants during each exercise and this was done by communicating via light signals through the practice tool. We aimed at building a form of *partnership* that could instil a *sense of belonging* by supporting the patients to safely integrate Edo into the daily routine at home and this was done by signalling when it was time to exercise through the disc-shaped component.

Evaluation

The interview results are presented here in short descriptions reporting participants' experiences of Edo concerning its character, the collaboration it affords and the partnership it intends to establish over time. For each aspect, the results of participants' experiences are summarized first, after which a reflection is given on whether these results correspond to the design rationale. Quotes supporting these descriptions are presented in Table 2. Each section ends by briefly discussing the usefulness of the design concept.

Character

Participants highlighted how they experienced Edo's focus on empathizing with their current situation by providing them with the discipline to keep on training every day and supporting awareness of the positive value of such activity, like discovering opportunities for functional arm-hand movements in daily life (e.g., opening the lid of a jar). Edo came across as not complicated.

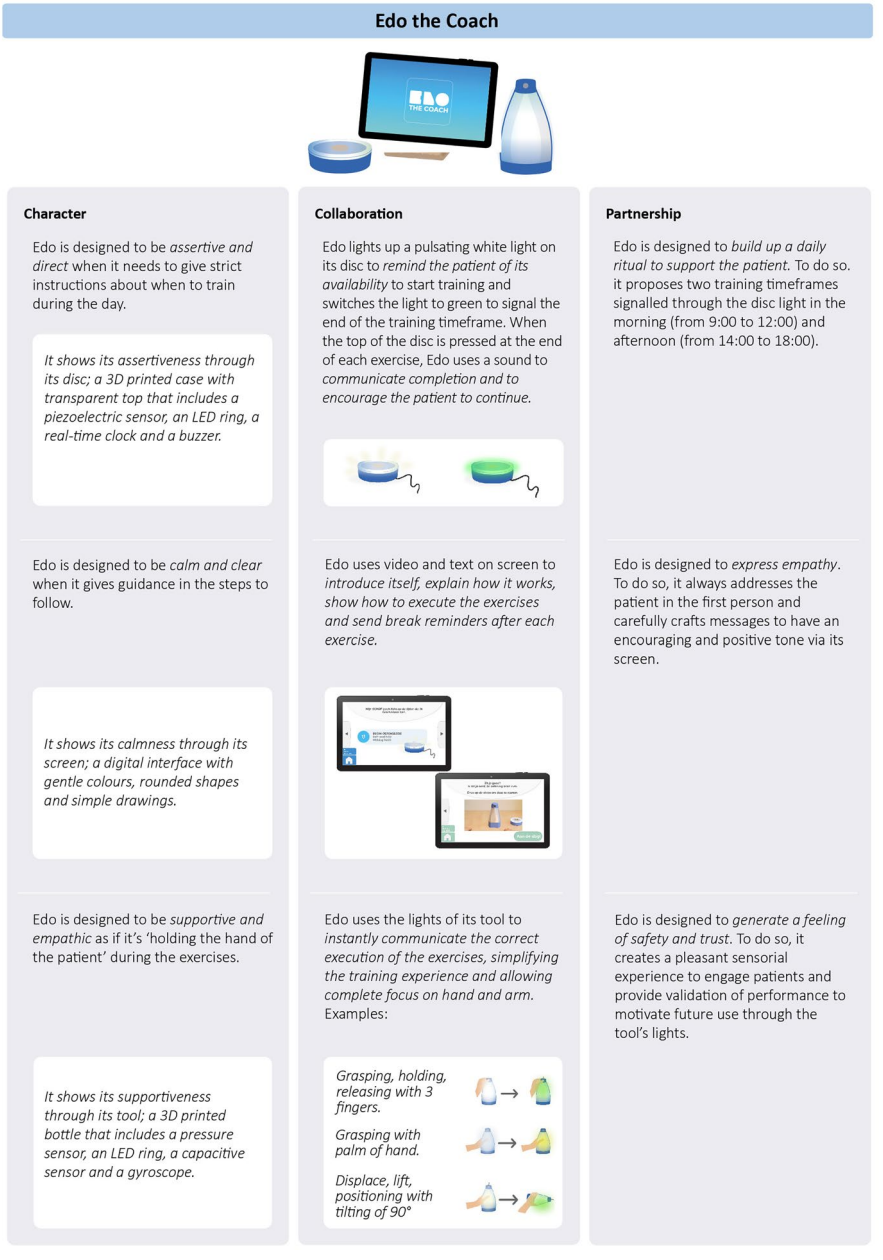

Figure 5. The embodiment of Edo in relation to its intended motivational qualities and social relatedness.

Participants understood that Edo alerted them through its disc when it was time to start training and that the next exercise was activated by pressing the top of the disc. Explanations Edo gave through its screen about how to do the exercises were clear and experienced as calm. Participants felt that Edo physically engaged them during training and rewarded them by displaying light upon completion if the movement was performed as expected.

Table 2. Participant opinions about Edo.

Design concept	Design feature	Quote
Character	Discipline	'If you haven't got Edo, you think oh, I'll do it tomorrow.' - P1
	Empathise	'It's not a strict thing, it's friendly. Really a helpful coach.' - P9
	Think in terms of opportunities	'I thought "I've never tried that before" […] then you go and see I can open more jars, tubes and things like that.' - P7
	Level of complexity	'It was easy to use because it was simple.' - P7
	Edo alerts (Disc)	'The light goes on, as […]a reminder that you have to do it now.' - P9
	Indicate begin/end exercise (Disc)	'I liked the disc […] because you could put your fingers on it […] and the exercise was finished with that.' - P3
	Explain clearly (Screen)	'It is clear what you should do and not.' - P3
	Shows completion (Tool)	'It changes colour when you have to finish the training, that's good.' - P1
	Shows correctness (Tool)	'Obvious, if you hold it right it turns green.' - P7
Collaboration	Embed in the home	'It fits. It's standing here and you don't have to change a lot in your house.' - P1
	Location at home	' [In the living room] you see it clearly..' - P6
	Easy to follow	'It is easy, because you can see exactly what you have to do.' - P8
	Easy to learn	'It doesn't take a lot of time to learn it.' - P10
	Easy to remember	'Easier than exercises […] on just a paper, without images, etc. I have to remember those exercises by myself.' - P6
	Step-by-step guidance	'I want guidance. […] I expect a coach to tell me what to do.' - P2
	Focus on the hand	'I cannot feel what this hand does, so I need to look at the hand.' - P2
	Feedback movement	'Now you don't know if you're holding it right. You don't know how hard you should squeeze it. […]' - P4
	Monitor posture	'It would be good to see where the elbow and the shoulder are supposed to be. […] because it is really easy to get yourself an injury..' - P2
	Fit daily plan	'I wanted to get it done before the coffee.. – P7
	Allow autonomy	'Maybe you can set the time yourself. I work from five to six, so that you could do something beforehand and afterwards.' - P1
Partnership	Sense of/improvement	'If he indicates that I'm doing well, you can get a better connection.' - P1
	Personalized experience	'It has to be something that you want, your own goal.' - P10
	Increase challenge	'If you can already do it, it becomes boring.' - P1
	Combine with other activities	'I have other practices from physiotherapy as well.' - P6
	Align with therapist	'When the therapist tells you what to do in this training, then that's ok. Edo has to work with the therapist' – P1
	Create a habit	'You get a hang of it, a rhythm.'- P4
	Encourage	'It's nice when he says: "Hey, it's going better now than the first time." Or perhaps he can work with numbers.' - P1

According to what participants shared, the expressivity of the different components influenced the understanding of Edo and its intentions and helped in balancing traits of 'humanness' and 'thingness'. Compared to the concept coaches of Phase 1, which embedded many human-like features, Edo had less, but was still perceived as technology that expressed intentions, could display personality and provided a *sense of intimacy*. This helped participants to accept Edo as a piece of technology in their homes without it being considered to be a medical device.

Collaboration

Edo behaved consistently and clearly explained what to do. Edo's video instructions showed the purpose of training and helped establish a clear and shared

goal with the stroke survivors from the beginning. The instructions were deemed easy to follow, and the exercises were easy to learn and remember because participants could see what to do instead of reading instructions. However, participants expressed that they would have liked to be guided step-by-step and be provided with a specific number of repetitions to maintain the expected training intensity for their level. In communication with Edo, participants missed real-time feedback on their posture and shoulder position before and during the exercise, as they considered it the most difficult aspect to control.

Participants felt like Edo was working together with them by helping to maintain the focus on the movements they were performing, thereby creating a *sense of attachment*. Visual feedback helped participants better understand how they performed the exercise while doing it. Still, they felt that Edo did not provide trustworthy feedback on their exercise execution. They could see that the expected result was achieved (i.e., the tool's light-activated) but not whether the movement was correctly performed (e.g., fast enough, with the proper pressure, etc.).

Edo showed to be flexible enough to fit into their routines, which was highlighted as a crucial point by participants already during the exploration conducted in the Concept phase. Nonetheless, the study highlighted the importance of allowing participants to maintain a sense of autonomy and control (e.g., setting up a preferred time for the training reminders). For example, participants were accommodating to Edo's exercise requests without creating too much of a disturbance, for instance by accepting doing exercises only at specific times and adjusting the duration of the training sessions. Participants found that Edo easily fitted in their homes. Some participants placed Edo in the living room to easily see the light signals emitted by the disc. Others kept Edo in a private room to not be disturbed by the family while exercising or to keep Edo's components away from the shared table in the house.

Partnership

Edo resulted in a more pleasant and approachable alternative than the solutions participants had experienced before. They also stated that if the interaction with a coach becomes an enjoyable daily ritual or habit they get attached to, it can help in easily committing to exercising for a longer time. To keep the experience engaging, participants suggested that Edo could also boost their mood by using empowering words in between exercises. All these suggestions would require Edo to adapt over time.

Participants stated that their sense of improvement and success within the rehabilitation trajectory correlates to their noticeable progress over time. In their opinion, Edo should have been able to propose exercises specifically fine-tuned to their current needs (e.g., daily activities) by agreeing upon the goals to reach together. They emphasized the importance of being given a training plan that adapts and develops over time, such as increasing the level of challenge more often.

Participants would have liked more freedom in adjusting the training time frames to their schedule to combine Edo's exercises with the rehabilitation activities given by the therapist so that it does not take too much time from the other exercises they are expected to do. This indicates how Edo is considered not to replace therapists but complement them: to trust and consequently keep using Edo, they expect it to work in parallel with the therapist. It can facilitate monitoring and fit into the rehabilitation therapy they are already following thereby instilling the feeling of security and support necessary to create a *sense of belonging*. Thus, Edo will not replace the stroke survivor-therapist relationship, it will help in trusting Edo as a mediator for supporting and facilitating such a relationship.

Discussion

We investigated how to design motivating social relatedness among an embodied agent and a patient in the context of at-home rehabilitation by designing them through the features of character, collaboration and partnership. In this section, we will first discuss how these learnings contribute to the work on Human-Agent Interaction (HAI) and Design. Then, we will reflect on the implications of this work for approaches and methodologies for designing technology in eHealth (and healthcare in general) is capable of creating social relatedness and its potential ethical concerns. We end with limitations and suggestions for future work.

Implications for HAI and design

This work enabled interaction between participants and embodied agents as an eHealth solution. Concerning the agent's character, participants made associations, read personalities into the coaches, and explained how this supported them in pursuing training. These reflections shows evidence of people's tendency to attribute personhood to inanimate objects (Heider and Simmel 1944) and connect to ongoing work on the animistic approach in design, in which human or animistic metaphors are applied to the design of interactive artefacts to make their computational intelligence more relatable (van Allen et al. 2013; Dryer 2010) and interaction more meaningful (Welge and Hassenzahl 2016). As narrative theory describes, an identifiable story character facilitates the transportation of readers/viewers into the story's world, positively influencing people's empathy and thereby relatedness with the character (van Laer et al. 2013). Identifiable agent-characters are therefore to address the need of *social relatedness*, thereby designing motivational relationships. For instance, we found that participants discovered in Edo a human-like aspect connected to friendliness and empathy as it was expressed by P9: *'It's not a strict thing, it's friendly. Really a helpful coach.'* However, developing a coherent personality for

Edo as a system that consists of multiple components (i.e., disc, screen and tool) turned out to be challenging at times, and not always easy to interpret. For example, P3 explained how the disc was seen only as a practical component to conclude the training but with no particular character associations were made: *'I liked the disc […] because you could put your fingers on it […] and the exercise was finished with that.'*

We could also identify some of the qualities of collaboration that embodied agents should afford rather than simply maximizing the user's control. The success or failure of the collaboration is influenced by the degree of autonomy allowed to the two parties in the relationship. This suggests a form of accommodation (Kluwer et al. 2020) of the behaviour of the agent and human, which can affect the quality of the human-agent relationship, just as it does in a human-human relationship, and in particular to establish mutual support (Deci and Ryan 2014). Thereby it allows for a form of *social relatedness* to arise, further supporting the design of motivational relationships.

We learned that tasks and responsibilities distributed between user and agent should have its basis in the needs of users, which are then aligned with the capabilities afforded by interactive technology (Hassenzahl et al. 2020). This provides a feeling of competence, further using the needs mentioned in SDT. The interactions we designed with the concept coaches and Edo can be considered to create a form of cooperative assistance (Krüger, Wiebel, and Wersing 2017), but also recalls the concept of 'agency play' used in game design, which details what actions are possible between the system and the user (Harrell and Zhu 2009).

Participants' reflections on the evolution of the collaboration over time, reveal the need for a partnership based on co-development, in which both human and agent learn from each other. Common goals and clear mutual communication between agent and human are expected to be productive in establishing motivational relationships (Cila 2022). Olson and Xu (2021) describe how novelty effects suppress minor defects of the agent during the first encounter; frustration can arise in the long term if the agent is not trusted to be competent enough to support the changing needs of the human. In human-human relationships, trust heavily influences the degree of autonomous motivation between two partners to be in a relationship and has consequences on the perceived quality of relationships (Kluwer et al. 2020). We propose that using the notion of partnership, which emphasizes development, commitment, and trust, may also be productive in fostering *social relatedness* and consequently the motivational relationship with agents.

Implications for design for rehabilitation and healthcare

In addition to considerations for human-agent interaction design within eHealth, this study shows relevant implications for designing within this

specific context of at-home stroke rehabilitation. We would like to highlight two important implications for designing within this context. When developing embodied agents as eHealth coaches, it is essential to allow stroke survivors to maintain a sense of autonomy (addressing the need for autonomy of SDT) and control and to be sensitive and adaptable to changed conditions or different needs (addressing the need for social relatedness and competence of SDT).

The sense of autonomy and control in stroke survivors has been described in the literature as a significant concept in life after a stroke (Lou et al. 2016). The perception of autonomy is affected by having a chronic disabling condition (Eassey et al. 2020) and being institutionalized (Proot et al. 2000). It is still challenged after being discharged (Palstam, Sjödin, and Sunnerhagen 2019). Furthermore, patients reported reduced autonomy in conventional rehabilitation, heavily relying on caregivers (Proot et al. 2000). Home-based eHealth solutions like Edo instead can help in providing greater flexibility, for example in therapy schedule and location. Therefore, although it is challenging to equal all the benefits of conventional therapist-patient relationships, eHealth solutions appear to bring advantages in terms of patient autonomy.

When designing an at-home rehabilitation tool for stroke survivors, finding the right balance between guiding the exercises while fostering autonomy is important to satisfy the users and motivate them to increase therapy participation. This study indicates that autonomy is positively addressed through the use of embodied agents that people can fit into their daily routines and align with personal treatment goals. The latter may require the adaptability of a coach over time.

Stroke survivors recovering from stroke follow specific recovery profiles (van der Vliet et al. 2020). Since recovery differs over time and between individuals (van der Vliet et al. 2020) with different arm rehabilitation goals and treatment preferences (Timmermans et al. 2009), stroke rehabilitation programs require adaptability, also at home (Langerak et al. 2023). This favours flexibility on the part of the therapist and/or eHealth technology for adapting therapy goals and strategies. For instance, augmenting Edo's capabilities by including technologies, such as wearable sensors or 3D cameras, to collect performance and health data, and the use of intelligent algorithms, can enable Edo and other eHealth solutions to adapt and provide personalized performance feedback (Hun Lee et al. 2023).

The three concept coaches described in the first phase of the study illustrate the need to keep the right balance between the intrinsic engagement with embodied agents and the medical purpose of the intervention (Siriaraya et al. 2021). In settings where vulnerable users are involved (D'Olivo et al. 2020) or mental care issues are addressed (Siriaraya et al. 2021), understanding this balance requires genuine collaboration with patients and caregivers. This appeals to the need for reframing approaches and methodologies in the design of healthcare technologies. Our study contributes in building

knowledge on how to design and introduce in context eHealth solutions capable to address the needs of patients previously described starting from a social relatedness lens.

Limitations

Our study presents some limitations. Due to the vulnerabilities of the targeted users (Vines et al. 2014), such as deficits in memory, cognition, and expression (i.e., aphasia), it was difficult to recruit participants. Some of the participants who had been included had difficulties reflecting on their experiences. We did not account for user vulnerabilities in this study, yet all participants, including those with vulnerabilities, were included to ensure a representative sample of stroke survivors. In future studies, a larger and ideally longitudinal sample can analyse meaningful subgroups based on user vulnerabilities mentioned here. Furthermore, the included participants may have been more motivated and interested in technology compared to the wider population.

Other study limitations may have been caused by some of the prototype technology. Participants often pointed out limitations imposed by the technology such as the tablet's speed and the lack of real-time feedback, for instance P4 mentioned: *'Now you don't know if you're holding it right. You don't know how hard you should squeeze it. […]'.* Therefore, in a future prototype redesign, the use of more advanced technological tools, i.e. a faster tablet and more sensitive sensors to detect movement could be beneficial for the study and the participant experience, as Edo will then feel more like an agent instead of a technological tool.

In general, through the participants' descriptions of Edo several positive aspects emerged such as: it was easy to follow Edo's instructions and the exercises proposed. Edo was reducing entropy and distraction by showing only what to do instead of requesting to read long instructions via text and by providing visual feedback (i.e., coloured light) directly near the hand instead of asking the participants to look at the same time to their arm/hand and the monitor. Edo was a good reminder and it was easy to keep it at home compared to alternative training solutions experienced before.

However, participants also highlighted specific challenges for which they shared potential improvements. They missed real-time feedback on their posture and shoulder position, which normally are pointed out by the therapist observing them during a session, and they couldn't see if all the movement was correctly performed in terms of speed and proper pressure. They had to test the prototype with pre-defined exercises that were not specifically fine-tuned to their current training level. Therefore, interesting improvements for Edo will include: the introduction of arm sensors and AI based feedback (e.g. encouraging words) to boost the mood according to the performance and the level reached by the patient, a 'responsive' training plan with the

number of repetitions that updates and increases in difficulty through time according to the achieved results; and a dashboard to freely setup the training schedule to combine Edo's exercises with other rehabilitation activities.

To ensure the safety and privacy of the user, we should also remember that eHealth solutions must comply with applicable regulations, such as the Medical Device Regulations and the General Data Protection Regulation in the European Union, before being implemented. A literature review (Jokinen, Stolt, and Suhonen 2021) emphasizes users' privacy concerns, advocating for data ownership and informed consent when sharing data among healthcare professionals. Additionally, the study underlines the importance of eHealth as a complement to human contact for addressing health issues, highlighting the need for competent professional support in its use. The absence of such support may contribute to inequality and injustice, particularly for those hindered by poor internet access, skills, and difficulty understanding digital services (Jokinen, Stolt, and Suhonen 2021), potentially affecting the sense of belonging and safety perceived by people in relation to the eHealth solution. However, there is very little empirical research on this subject (Jokinen, Stolt, and Suhonen 2021), and to the best of our knowledge, no research has been found on the emotional impact on users. Therefore, further development of EDO should also consider the users' perspective on eHealth ethics.

Finally, we can only speculate on the long-term impact (i.e., partnership) through the presented study. Investigating this would require a longitudinal study to exclude the novelty effect of introducing the coach (Gaver et al. 2003) and to evaluate the sustained impact and partnerships developed over an extended period. In this regard, after iterative evaluation and optimization of EDO's design, a randomized controlled study will be conducted to evaluate adherence and efficacy of a rehabilitation intervention with EDO compared to usual care.The effectiveness of stroke rehabilitation interventions for motor impairment is influenced by dosage (Lohse, Lang, and Boyd 2014) and highly associated with adherence (Gunnes et al. 2019). Establishing a long-term partnership that enhances perceived support and motivation for individuals with stroke has therefore the potential to positively impact rehabilitation outcomes of motor impairment.

To summarize the findings of the work here presented contribute to the design of embodied agents for home rehabilitation by highlighting that (i) the design of eHealth technology meant to be introduced in sensitive contexts like the one of people undergoing rehabilitation after stroke, benefits from the use of interactive features that help embodied agents to express intention and personality to instil as sense of intimacy between the user and the agent and consequently remove medical device connotations, (ii) technology for stroke rehabilitation introduced at home in the form of embodied agents should be easy to follow without the help of a therapist and should keep visual and sensorial inputs at the minimum to help focus (e.g. lower level of gamification

and playfulness), provide clear and direct explanations, follow the patient in each step of the execution of the training, offer real time feedback and be adjustable to the rhythm and habits of the people without becoming invasive also in their living context, hence contributing to instil a sense of attachment between the user and the agent. Finally, (iii) embodied agents should not be designed to replace the stroke survivor-therapist relationship or presented as the ultimate solution, but be introduced as a mediator meant to support and facilitate such a relationship contributing to create a sense of belonging.

Conclusion

In this article, we explored how social relatedness can be used as a concept to create motivational relationships with embodied agents in the context of home-based rehabilitation. We can conclude from the research that it is possible to design both the character of embodied agents and the interactions they afford in ways that are experienced as motivating with the potential to develop towards partnerships with people, although the latter could not be assessed directly. Social relatedness translated to aspects of the design in different ways, from being supportive yet strict, empathic and objective in providing feedback, clear in communication or by establishing shared goals and adjusting to changing needs. An important consideration in the design of embodied agents through a socially relatable lens is to find the right articulation of humanness and thingness: Too much human resemblance can make them childish and overly imaginative while having too few human annotations might lower their socially motivating appeal. Because rehabilitation processes are often long, require commitment, and develop and change as patients progress, eHealth solutions that establish longer-term relationships are becoming essential. The results of this study can therefore contribute to the design of embodied agents that foster therapy participation in home-based rehabilitation.

Notes

1. The clinical stages of stroke are: acute stage (1–7 days post-stroke); early subacute stage (7 days to 3 months post-stroke); late subacute stage (3–6 months post-stroke); chronic stage (more than 6 months post-stroke).
2. Ibid.
3. Ibid.

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Appendices

Appendix 1. Interview guide.

Introduction
a. Session goal and context b. Value of participant's opinion c. Consent form d. Session overview
Looking back at the experience of being a stroke survivor
Exercise 1: can you explain WHO MOTIVATES YOU TO TAKE CARE OF YOURSELF? Are there friends, relatives, acquaintances or colleagues with whom you like to do things for yourself? Are there people who support you in your rehabilitation? How did this person help you? Exercise 2: can you explain WHAT TECHNOLOGY MOTIVES YOU TO TAKE CARE OF YOURSELF? Are there any apps you use or have used for your mental or physical health? This can also be done in combination with a physical device such as a Fitbit or Nintendo Wii. Find, or think back, tools (apps, devices, or combinations) that you like to use and that you don't like (or didn't) use.
Introduction general scenario
a. Learn to interact with the coach in the clinic during the last week of rehabilitation b. Therapist installs the coach, so that it is personally adapted to you c. Bring coach home at the conclusion of the week d. Coach requires interaction of 1 hour for 5 days a week. e. At a fixed moment you grab the components to do the exercises and finish. f. Weekly review, adjust g. After 6 weeks back to rehabilitation centre > completion therapy or adjust program to continue
Concept 1: Coach boot camp
Enactment a. You are somewhere in the house, and then you hear… (whistle sound) > 'time to exercise!' b. Go through paper prototype, including performing exercises together Conversation a. What do you think of this coach? • What do you associate the coach with? • How would you describe the personality? • What appearance does the coach have? b. What do you like and what not? c. How did you find the communication and interaction? • Would you ignore the coach? • Does the coach take sufficient leadership? Or do you want to be more in charge? • Did unexpected things happen? Did you expect something different? • How did you feel while using it? (motivated, energetic, confused, uncertain etc.) • How did the tools feel on your body? d. Would you use this coach? e. What motivates you to use it? f. What exactly does not motivate you? g. What do you think about getting a badge and comparing it to teammates? Does this make you want to continue? Or not? h. What do you think about the way you can see your progress (collecting badges)? i. Does the coach provide support in contact with the therapist? How?

(*Continued*)

Appendix 1. Continued.

Introduction
Concept 2: Magical Training Objects
Enactment a. You are somewhere in the house, and then you hear … (Siri sound) > the training starts. b. Go through paper prototype, including explaining exercises only through sound Conversation (*See questions presented for coach 1)*
Concept 3: Arm Buddy
Enactment a. You are somewhere in the house, and then you hear … someone saying: 'Hi… it's time again. Here I am!' b. Go through paper prototype, including showing exercises first and then let participant perform exercises Conversation (*See questions presented for coach 1)*
Closing
Compare a. Where would you place a coach like these 3 concepts in your home? Think back to sensitizing. b. When in the day would you do the exercises? c. Is it nice to get acquainted in advance? Or would you really like to discover the tool at home? Choose a personality a. How would you describe the character, personality of each coach? b. Which one appeals to you the most? Which one do you have the most pleasant relationship with? Why? Possible developments a. Which coach would motivate you the most to do the exercises? b. Would the coach motivate you for 6 weeks? Why? c. How would you like to finish? d. What do you think could be improved?

Appendix 2. Interview guide.

Warming up
a. What was it like to have Edo at home for a week? b. Could you share interesting moments you had with Edo this week? - *e.g., please describe or show to us what happened;*
About Edo's character
a. How would you describe Edo to one of your friends or to a family member that doesn't know it yet? b. How would you describe Edo as a kind of coach? - *e.g., style or approach, manner of conducting you, way of speaking to you;* c. How would you describe the behaviour of the different components of Edo? d. What do you like or do not like about its design? - *e.g., materials, appearance, style, etc.;* e. How did you experience using Edo as a coaching system? - *e.g., usability, communication, enjoyment;* f. What would you like to change about Edo's design? - *e.g., specific component, in the interface;*
About collaboration with Edo
a. Could you talk about how you experienced doing exercises with Edo? - *e.g., when and how often;* - *e.g., difficult / hard;* b. Where did you do the exercises with Edo? - *e.g., where did you place Edo when you did not actively use it;* c. Did you feel like you could count on Edo in doing and performing these exercises? d. Did you use Edo in different ways than instructed? e. How did the use of Edo fit into your daily routines? - *e.g., length of the exercises;* - *e.g., possibility to repeat the exercises as many times as you wanted;* f. Were others involved in the use of Edo for exercising or otherwise? g. What would you like to change about how Edo's allows you to exercise?

(*Continued*)

Appendix 2. Continued.

About partnership established with Edo

a. Could Edo motivate you to do the exercises? If so, how?
b. How would you rate the motivation triggered by Edo from 1 (Lowest) to 10 (Highest)?
c. How could Edo motivate you even more?
d. Did you find Edo useful as a coaching system at home? If so, why?
e. Do you think you can trust Edo as a coach? What would help you to trust Edo more?
f. What should Edo do to build up a relationship with you over time?
g. Would you recommend it to other people undergoing rehabilitation?

Appendix 3. Participants overview.

Concept phase

Activity	Participant	Gender	Age	Stroke occurrence	Arm/hand function (UAT*)
Participatory session	P1	Male	51	2020	5
	P2	Male	59	2021	6
	P3	Male	63	2014	4
	P4	Male	60	2011	7
	P5	Male	46	1987	6
Interactive interviews	PF1	Female	46	October 2021	6
	PF2	Female	33	July 2021	6
	PF3	Female	61	August 2021	7
	PM1	Male	56	September 2021	6
	PM2	Male	72	October 2021	5
	PM3	Male	70	August 2021	3

Prototype phase

Activity	Participant	Gender	Age	Stroke occurrence	Arm/hand function (UAT*)
Home field study	EP1	Male	54	August 2020	6
	EP2	Male	60	August 2019	5
	EP3	Male	61	December 2021	6
	EP4	Male	56	August 2021	6
	EP5	Male	63	January 2018 September 2021	6
	EP6	Male	76	October 2021	6
	EP7	Male	69	November 2021	6
	EP8	Female	49	September 2021	5
	EP9	Male	39	January 2022	6
	EP10	Male	69	January 2021	4

*UAT: Utrecht Arm Test score (Range: 0–7, where 7 indicates all arm movements are possible, but the affected arm is clumsier compared to the other arm); a bedside test quantifying arm function in stroke survivors.