Bsc Creative Technology
Thesis Project

Designing a socially assistive robot, to aid in healthy loading for people with knee osteoarthritis.

Suzanne Rutten

Supervisor: Anouk Middelweerd ad Sebastian Schneider

June 11, 2025

Faculty of Electrical Engineering,
Mathematics and Computer Science,
University of Twente

UNIVERSITY OF TWENTE.

Abstract

Osteoarthritis (OA) is the most prevalent degenerative joint disease worldwide, with knee osteoarthritis (KOA) being especially common due to aging populations and rising obesity rates. Current management strategies often include medication, education, exercise, and technological interventions. However, the adoption of innovative solutions like social robots to support self-management and symptom alleviation remains underexplored. This research investigates how social robots can aid in KOA symptom management through guided exercise and behavior change techniques (BCTs). Following an introduction to KOA's pathology, symptoms, and conventional remedies, the background research delves into technological advancements and the evolving role of social robots in healthcare. Social robots, defined as physically present systems capable of socially interactive feedback, have shown potential to alleviate both physical and emotional distress while supporting patients in long-term symptom management. These robots also facilitate engagement by leveraging auditory and visual feedback, personalization, and emotional connectivity.
The methodology combines personas, brainstorming, and the MoSCoW prioritization method, integrated within the Creative Technology Design Process. This structured, iterative approach encompasses ideation, specification, realization, and evaluation. Personas were developed to encapsulate user needs, ensuring the final solution is intuitive, supportive, and adaptable to the target group. The ideation phase explored a range of concepts, narrowing to feasible and impactful solutions via convergence and benchmarking against user-centred requirements. Behaviour change techniques were integrated, including; action planning, instruction and demonstration of behaviour, behavioural practice and graded tasks.

The realization phase involved the development of a high-fidelity prototype featuring three core functions: health dialogue, a guided yoga routine, and supervised exercise coaching. NAO, a humanoid social robot, was employed to demonstrate exercises, assess user performance through posture analysis, and provide immediate feedback to improve accuracy and motivation. These functionalities were developed using Choregraphe and Python, supported by motion capture systems(mediapipe and cv2) to analyse and refine user-robot interactions.

Evaluation was conducted through user testing with semi-structured interviews, the Attrakdiff questionnaire, and think-aloud sessions. Results revealed adequate usability and positive user experience. Key findings indicated the importance of instant feedback, enjoyment during interactions, and adaptive features aligned with user preferences and physical limitations. The prototype effectively demonstrated its potential in addressing KOA symptom management. Although further testing is required.

The discussion highlights strengths, including the robot's ability to blend physical activity guidance with behaviour change support. Limitations include limited evaluation, lack of pre-existing evidence of safe joint loading, and limitations to the robots capabilities. Future work emphasizes refining technical capabilities, further user testing, and further integration of activity tracking devices.

In conclusion, this study establishes the feasibility and user acceptance of social robots as supportive tools for KOA management, blending physical exercise with innovative technology and user-centred design principles to promote self-management through exercise.

Acknowledgements

I would like to thank my supervisors Dr. Anouk Middelweerd and Dr. Sebastian Schneider for the opportunity to work on this project as well as their support and time.
I would also like to thank the experts I interviewed, for the insights they provided into the project. Additionally, I am grateful to my user test participants, your input is much appreciated and a valuable addition to my research. Furthermore, I would like to thank the employees of the interaction lab for their help and guidance on devices.
Lastly, I would like to thank Demi van Bommel and Milou de Zwaan for their support and suggestions for improvement.

List of Tables

List of Figures

Contents

1 Introduction

Osteoarthritis (OA) is known to be the most common degenerative joint disease in the world [8]. In the Netherlands alonean estimated 4.5-9.4 percent of men and 7.7-14.0 percent of women have knee osteoarthritis (KOA) making it the most commonly affected joint. Two of the biggest risk factors are obesity and advancing age [9]. With the population getting older[10], and more more and people turning obese [11], the prevalance of OA will only rise. It is a disease which causes the ones affected to suffer constant pain in their joints especially after movement [9],[12]. Luckily for these people there are ways to live with the disease. For a long time it was medication to manage the pain in early stages, or joint replacement for later stages of the disease. However, these joint replacements are not without consequences [8].

Often less intrusive solutions are recommended as a first self management solution, educating people who suffer OA on the disease can help them learn how to better manage their symptoms [13]. Additionally, exercise can help reduce the pain felt in a joint, in a similar way an anti inflammatory medication might do so [14]. However, people can be afraid to exercise as they fear they might exacerbate their symptoms by using the joint [15]. Hunter et al. [16] state that there is no strong evidence that allows the claim that exercise can worsen KOA symptoms. Mcalindon et al. [17] even state that exercise has a positive effect on pain reduction, what type of exercise does not matter. Although there is no one landbased exercise they claim to be advantageous they suggest a combination of range of motion (ROM), strength training, and aerobic movement for pain reduction.

Currently there are many technological interventions available. These interventions mostly focus on preventative measures. Many of these advancements are telecommunication applications such as, mobile apps, or video calls with doctors [18]. However, johnson et al. [19] call for technologies which are easier to use than those out there as of now. A social robot (SR) combines both the preventative health-care (exercise) and ease of use (social interface). Due to their social interface, where a user tells it what it wants and the bot interprets it, a social robot would be a great solution.

Social robots are a widely discussed topic in tech, and thus has many ways to define it. First Fong et al.[20] supply that a social robot is a robot which is capable of social interactions. Meaning that it is able to communicate something to a user and receive communication back from said user. Feil-Seiffer and Matarić[21] add that a socially assistive robot(SAR) specifically assist its users through these social interactions. Fasola and Matarić [22] and Bishop et al.[23] agree with Feil-Seiffer and Matarić. However, Fasola and Matarić [22] add that this assistance happens through no-touch-interaction methods; speech, body language, and facial expressions. While Bishop et al.[23] state that SARs are there for both physical and mental support. Although the exact ways in what these SARs are socially assistive, there is a consensus on what they do. These robots assist their users through the use of social interactions to help them through their engagements. Hence the definition for a SAR in this paper will be a physically present robot which assists its users using social interactive way through auditory or visual feedback.

A social robot allows for personalization of care, as its main form of interaction is social. This adaptability and personalization of care for KOA patients is important as no one person is the same, the same holds for their disease [13]. By developing a social robot which helps its users exercise, a solution which aids its users in their own symptom management might be achieved. This leads to the following main research question and the subsequent sub-research questions:

- **How might a social robot be designed to aid in the self-management of KOA pain symptoms in patients through socially assisted exercise?**
- What are symptoms of KOA and how might these be managed?
- What are applications of social robots?
- What strategies might help in making healthy and safe exercise standard behaviour?
- How can BCTs be incorporated into a social robot?
- To what extent is the social robot usable and user experience friendly in its aim to help manage KOA pain through guided exercise?

The main question asks how a social robot might be designed to help patients with KOA manage their pain symptoms through socially assisted exercise. To answer this, the supporting questions each contribute specific insights.
First, understanding the symptoms of KOA helps to clarify the challenges the robot needs to address, such as pain, stiffness, and reduced mobility. This ensures the robot's design focuses on the most important aspects of the condition. Next, exploring how KOA symptoms are typically managed provides a foundation for the robot to incorporate proven approaches, like specific exercises, lifestyle adjustments, or other symptom management strategies that are known to be effective.
Looking into the applications of social robots highlights the roles they can play in patient care. For instance, social robots can offer guidance, motivation, or emotional support, which can make them valuable companions in encouraging patients to follow through with their exercise routines. Additionally, considering strategies that promote healthy and safe exercise behaviours ensures that the robot is designed to motivate patients effectively, helping them stick to a regular exercise regimen while prioritizing safety.
Finally, evaluating how usable and user-friendly the robot is allows for a focus on accessibility and adaptability. This ensures the robot is easy for patients to interact with, even for those who may have physical limitations or less experience with technology. Together, these questions provide a framework for designing a social robot that is effective, engaging, and tailored to the needs of KOA patients, ultimately making it a valuable tool for self-management.

2 Background research

2.1 Osteoarthritis

Osteoarthritis (OA) is known to be the most common degenerative joint disease in the world [8]. It is a disease which affects the joints, by; degradation of the cartillage in the joint, alteration in the adjacent bone and inflammation of the surrounding tissue [12]. There are multiple types of known OA; post-traumatic, ageing-related, genetic and symptomatic. However, recently a new type, 'metabolic OA' was determined to be related to metabolic syndrome (metS) and obesity[24]. It is most common for symptomatic osteoarthritis to be diagnosed. However, radiographic osteoarthritis can also be diagnosed. This is a type of osteoarthritis in which a patient does not have symptoms, but in an x-ray image shows clear degradation of joint cartilage [12].
According to Arslan et al.[25] symptomatic osteoarthritis in the knee might occur in four point five to nine point four percent of men and seven point seven to fourteen percent of women in 2019 in the Netherlands, making it the most commonly affected joint. Although the hands and spine are also commonly affected, any joint in the body may be affected[9]. Risk factors for OA include; genetics [9], gender (60 percent of the OA patients are women[26]), past trauma, advancing age and obesity [9]. Obesity and old age are more prevalent than ever. Obesity was declared an epidemic by the world health organization in 1997. 38 percent of the world population is obese or overweight, and it is projected that by 2030 78 percent of Americans will be overweight or obese [11]. The world population is also ageing, the number of people aged 65 years or older will grow from 761 million in 2021 to 1.6 billion by 2050 [10].
OA was previously thought of as a disease caused by 'wear and tear', where only trauma or repeated over exertion broke down the cartilage and depleated the synovial fluid in the joint. Recently it has become known that the disease is much more complex ,and in addition to the mechanical factors, a consequence of inflammation and metabolic factors[27]. This inflammation can be caused by a multitude of factors such as; abnormal body composition, adipokines, cytokines, complements, lipids and vitamin D [24].

2.1.1 symptoms or pathology

The most common symptom of OA is pain in the joints [9]. This pain often appears in two different ways; a constant pain or ache noticeable in the background of daily life and sporadic intense pain. The pain also steadily grows over time [27]. In case of persistent pain a person might also experience pain related psychological distress [28]. This pain is not only a result of use of the joint but can also be influenced by other factors such as; psychological, sleep, and nutrition.
According to Wise et al. [29] a worsened mental state also worsened the pain knee osteoarthritis patients experienced. And a worsened mental state increases the risk of a pain flare in the week there after. Lautenbacher et al. [30] state that sleep deprivation increase hyperalgesic, increased pain sensitivity, change. Elma et al. [31] state that nutrition is deeply influential in the perception of pain.
Aside from joint pain some other symptoms can be recognized. Stiffness may occur after a period of rest, which might also increase pain levels [32]. Another name for the aforementioned stiffness is the gelling phenomenon [9]. As a consequence of both this pain and stiffness people in the late stages of OA eventually are debilitated[8]. In addition to pain an often occurring symptom is inflammation. Recent studies have shown the presence of

synovitis[1], these studies have also shown a direct relation between inflammation of the joint and the progression of OA[26].A persons joints might also swell and lose mobility/ lose range of motion in the joint[32],[28]. A depiction of how an affected knee joint may look compared to a normal knee joint is shown in figure 1.

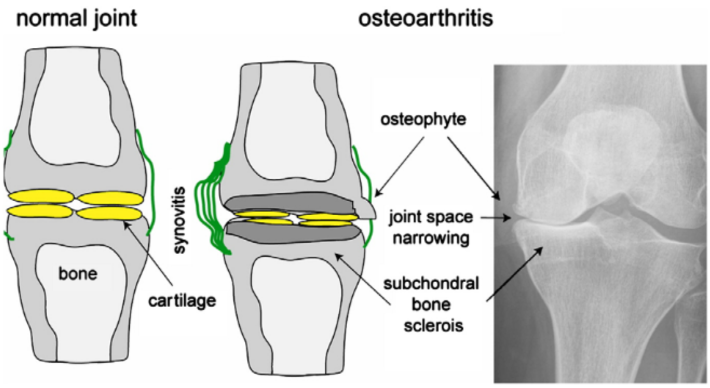


FIGURE 1: *A comparison of a normal joint versus common symptoms in a joint affected by osteoarthritis, also a representation of these symptoms in a x-ray image* [1].

Another way in which the joint morphology might change is through bone remodelling. Early on in OA there is a tremendous increase in subchondral bone tissue remodelling. the rate of mineral apposition is about five times higher compared to normal remodelling. As a consequence bone density decreases, porosity increases, and bone mass decreases. In the later stages of OA the rate of remodelling decreases, leading to higher bone density and more bone mass [34].

2.1.2 Current remedies

There are several options for the treatment of osteoarthritis. They fall into four overarching categories; non-pharmacological, pharmacological, complementary and alternative, and surgical [9]. However, most important is that the treatment is personalized as the condition is different per individual [13].

Pharmaceutical options are the most common line of treatment [8]. Often paracetamol and non-steroidal anti-inflammatories are used for a period of time to control symptoms [8]. A risk of these drugs is Non steroidal Anti-inflammatory drug induced gastrointestinal injury [35],[13]. Additionally, these drugs are limited in their efficacy of pain reduction [36]. Another option is intra articular corticosteroid injections, which has evidence provided that it relieves pain for up to two weeks. There is also noticeable improvement after 16-24 weeks [37]. to relieve pain Supplementation with omega-3 and/or EPA and DHA have been shown to block the expression of genes which are pro-inflammatory and block the deterioration of cartilage [14]. As of now the most innovative approach for treatment is tissue engineering. This technique is applied to both chondrocytes and mensenchymal stem cells (MSCs), which can then be used to repair lesions in joint cartilage [32].

[1]Synovitis is the inflammation of the synovial membrane surrounding a joint, which is often painful and characterized by joint swelling because of synovial thickening or effusion[33]

There are also more alternative options which can be associated with homeopathic therapies. pulsed electromagnetic field (PEMF) is an example of such. According to Wu et al.[38] PEMF greatly improves a patients daily functioning without increasing either pain or stiffness . transcutaneous electrical nerve stimulation is another such therapy, often used for severe pain. It has also been proven to be useful for OA patients in combination with exercise [39]. In combination with exercise Low-level laser therapy has proven useful to patients with OA in the knee [40].
Another option is Balneotherapy, which is more widely known as spa therapy or mineral baths, is another option. Although its efficacy is limited it has been shown to work, in admittedly not methodologically sound research [9]. Acupuncture is something patients have also been reported to be helpful. However, it has to be researched further before such claims of its succes can be made confidently [14].

The most invasive option is surgery, hence it is almost always treated as a last resort. The most effective surgery is complete joint replacement, which has yielded great results for the; hips, knees, and shoulders. Current prostheses perform well up to 15-20 years [28]. There are other surgeries in existence as of now but they are not as effective as total joint replacement, for example; Arthroscopic debridement for knee OA has been used in randomized trial but this did not yield better results than full joint replacement[14]. However, bio-engineering and tissue engineering are opening doors for new types of surgery where the joint might not have to be replaced in its entirety, rather reduce the risk or symptoms of the disease in the long term [8].

Under the non-pharmacological branch of treatment there are several options. First of all the patients could be educated on the disease. there are courses which the patients can follow on how to manage their disease. Their participation in this has been proven to be useful [13]. Obese patients could work on weight loss to reduce the chance of developing OA [8]. Exercise is already recommended in aiding the recovery of knee OA, to improve knee mobility and reduce pain in the joint. Moreover, exercise can be used to reduce pain in a similar way anti-inflammatories do [14]. Physical therapy (PT) has also been proven to help reduce pain and disability. the strengthening of the quadriceps through PT has had benefits for knee OA. Knee OA pain has also been shown to be effectively managed through the taping of the joint [36].

2.1.3 Knee osteoarthritis and movement

As mentioned before Knee osteoarthritis is one of the most common forms of OA [41]. It is often a result of obesity. To reduce symptoms caused by obesity a person could exercise with the goal of weight loss in mind. This might even reduce their need for later surgery on the knee joint [42]. Another common cause for knee OA is a pre-existing condition damaging the joint. An example of such is meniscus[2] damage, this condition might lead to OA. This could also be managed by weight loss and/or exercise [44].
The symptoms of knee OA most often increase while weight is put on the joint and decrease again when this weight is removed [45]. Some people believe or rather fear that exercise or movement can exacerbate their OA symptoms [15]. Quite the opposite is true. Willick MD and Hansen MD[46] discern that low-to medium-distance running has no causality in OA. Additionally, Hunter et al.[16] conclude that there is no strong evidence that vigorous

[2]"The medial meniscus is a crescent-shaped, cartilaginous band between the medial tibial and medial femoral condyle. The primary function of the medial meniscus is to decrease the amount of stress on the knee joint."[43]

low-impact exercise accelerates the development of OA.
Bosomworth [15] agrees and adds that moderate exercise could even reduce pain in the knee and disability. Mcalindon et al. [17] discern that different types of land-based exercises or movements are beneficiary to pain reduction in knee OA. They state that a combination of range of motion(ROM) exercises, strength training and aerobic activity all had a general positive effect. There is no strong favourability to be distinguished between these types of exercises[17]. Aquatic exercise might also be helpful in slightly reducing pain and disability and may improve quality of life directly after the treatment course [47].
Nevertheless, some research suggest that over exercising can exacerbate the disease. Exercise which might cause injury/trauma should be avoided [15]. People performing elite sports, especially high chance of injury sports, might have an increased chance of developing OA[16].
Exercise should be seen as a helpful tool in the management of OA. People do not have to be afraid of developing OA or worsening their symptoms of OA by performing low to moderate exercise activities, as there is no strong evidence supporting the claim of its negative effects.

2.2 State of the art

2.2.1 Technological interventions (TIs)

With the current pressure on health-care workers [48], technological medical advancements which take work away from these workers are more than welcomed. Such advancements are also there for OA. Most TIs, in this case mobile Health, are focused on data measurement and education of its user, while self management is an important aspect of OA symptom management[49]. However, Johnson et al. [19] argue that current interventions include applications for smartphones and/or tablets, which have been shown to increase exercise, reduce pain and opioid use for pain management. Additionally, Chen et al.[50] state that the delivery of an exercise program lasting 4 weeks to 6 months over a multitude of digital media, appears to offer benefits to patients.
Haptic feedback, which is used to provide feedback to correct a persons gait or stance, also helped reduce symptoms[51], [52]. However, once a person is provided with more than one haptic sensation at a time they struggle to notice them all and tend to focus on only one of these cues. Which suggest that the vibration should be limited to one joint, which makes gait retraining difficult [18]. Another treatment is neuromuscular electrical stimulation(NMES), which is where a persons muscles are directly electrically stimulated. Research on this is limited and divided about its effectiveness [18]. Virtual/augmented reality has also been researched. A real time biofeedback and avatar displaying tablet had a high adherence rate and scored well on its usability [53]. Which suggests real time feedback might be of importance. Robots can also be aplied for OA symptom and lifestyle management. They might; relieve pressure from health care workers and/or OA patient care takers, reduce OA related physical and emotional distress, reduce need for long term health care support and surgeries, and especially support the high support needs patients[54]. However, much more extensive research needs to be done for this to be stated with certainty.
Clinicians agree that technologies could add to the treatment they provide. Additionally, it could help with treatment compliance from the patients and could help in planning the correct course of treatment [55]. Shah et al. [56] agree that technological advancements help improve patient treatment and attach that digital health, relating to; patient educa-

tion, physical activity, and exercise intervention, is as effective as traditional strategies. The use of technology for OA lifestyle management is currently mostly based in telecommunication and commercially available load measuring devices. Which leaves a large gap in the market for a type of real time feedback technology [18]. Cudejko et al. [57] also call for further investigation of wearable technology for self management for OA. A concern noted by Johnson et al. [19] is the user accessibility, often the devices or applications used for OA self-management prove difficult to navigate for the patients or clinicians involved. However, patients are generally positive of the implementation of technology to manage OA symptoms.

2.2.2 Social robots

Social Robots are machines of the new age. They are autonomous machines that can emotionally connect with and communicate with human beings. They differ from inanimate computers in that they follow social behaviour patterns, have varying '*states of mind*' and adapt and learn through interaction. They are often humanoid as their shape is fundamentally important as their purpose is to emotionally connect to a human, this shape makes that more likely to happen [58]. These social robots are applied in a new range of ways/ According to Reeves and Nass[59] people treat computers the same way they would treat another person. They also argue that the social interface is the best interface. Consequently Breazeal[60] argues that social robots are a good fit for this purpose with their humanoid form, as they are built for this exact purpose. They are capable of facial expressions, body language, gaze direction and can use their voice. Which are all great examples of the natural human communication modalities . These modalities can also be used without the robots voice to communicate a message, for example the facial expressions or gestures the machine makes [61].
Obviously, social robots are more complex than just a single interaction. The person they assist might grow attached to the robot. Leite et al.[62] state that although the sample size of the studies they have reviewed were small, the application of social robots in therapeutic and health-related scenarios over a long period of time yielded positive results. People are more likely to form an emotional connection to a social robot over a longer period of time. Over time they are more open to disclosing information to the robot and feel more emotionally supported by the robots responses [63].

2.2.2.1 Osteoarthritis robots

Ray Marks [54] performed a literature review investigating the feasibility of implementing a social robot for osteoarthritis. In his review he has found that a social robot for osteoarthritis might, relieve some distress as well as carer burden and cost, might help highly disabled people be more independent, and reduce long term care needs. He does add that more extensive into this area is in direly needed.
Matthews et al. [64] developed a virtual exercise coach for KOA patients doing these exercises at home. They used accelerometers to measure movement of the patients/users, which was then used to determine the correctness of movement. Based on the correctness of these movements the virtual coach would provide feedback. The majority of these patients indicated struggling keeping up with these exercises on their own. They stated they were comfortable using the virtual coach and they thought the coach might be very useful for at home exercises.

Currently there are many applications of social robots out there which resemble a SR which might help manage OA symptoms. The pool of research into social robots for osteoarthritis specifically is extremely limited hence the investigation of other applications of SRs is pertinent to allow dfor the development of a comprehensive solution using a social robot to manage KOA symptoms . There are SR which aim to help guide physical exercise. There are also robots which focus on new skill learning and educating its users. The following types of robot (lifestyle and coaching) are examples taken from a very large pool of social robots from which some lessons can be taken.

2.2.2.2 Lifestyle robots

Tobis et al.[65] tested a social robot named TIAGo through the UNRAQ survey, they asked participants about; interaction with the robot, the assistive role of the robot, social aspects of using the robot, and ethical issues. The participants were between 68 and 86 years of age. After the participants interacted with the robot they had an overall positive acceptance of the robot, they were positive about the aforementioned roles of the robot. However, an entirely independent social robot for social support is not possible. Lastly, the older participants were able to relate to the functions and capabilities of the robot after more interaction.

Huisman and Kort [66] investigated the application of the care robot Zora over a 2 year period in dutch care facilities. The robot was introduced to health care professionals and clients/patients. During this longtitudal study it was found that there was a learning curve to the use of zora. Additionally, due to recurring issues in hardware and software the professional using zora developped frustrations which might have resulted in a less positive view of Zora in 2017 than the professionals had at the start of the project in 2016. The professionals had not anticipated the issues and how much time it would take to resolve these issues affecting their perception of Zora. However, they do state that when these issues are resolved Zora could be a useful addition to the quality of care. Through the application of zora they found that one-on-one activities and movement activities during rehabilitation. In the elderly care setting Zora is a welcomed asset.

Khosla et al.[2] Investigated the implementation of the robot Matilda, which can be seen in figure 2, in Australian elderly care facilities. They used two activities; group based and one-on-one interactions with matilda. The group activity entailed playing games, such as hoy, with the users and the one-to-one activities entailed dietary discussions. The study proved these implementations of matilda to be very effective in the areas of; quality, naturalness, and user satisfaction. In the concluding survey Matilda scored well on social interaction questions and activity questions, and the users expressed little concern in the use of matilda.

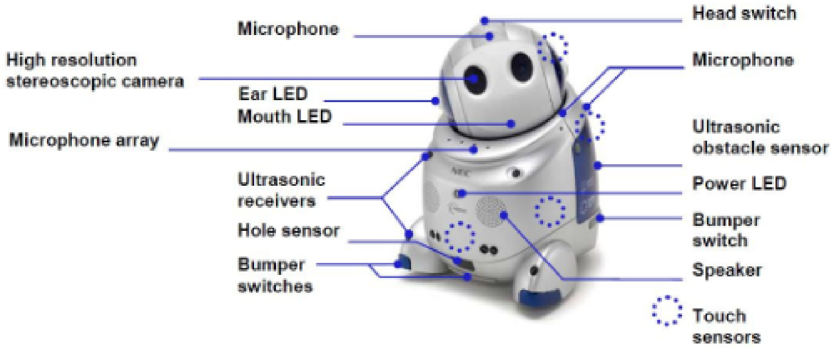


FIGURE 2: *the Matilda robot and its specifications*[2]

From these lifestyle robots a few lessons can be learned. It is important that the robot is not relied on as the single source of health care as they are not capable of operating as a stand alone health-care service. Additionally, as the robots are not meant to be operational as a single unit the robots should come with a guide or explanation protocol to ensure the robot is easily understood by users, professionals and clients/patients. These social robots are effectively applied in both group and one-to-one settings. Lastly, users learn through interaction thus the robot should adjust to the user during their learning process to ease the path.

2.2.2.3 Coaching robots

Tozadore et al. [3] looked into the effectiveness of a social robot which guides its users (university students) through a stretching break during their study sessions. Their participants stated they found the presence of the robot useful. However, some (6/20 participants) did think they could perform these stretches better without the robot. This idea might stem from the limited range of motion the robot it self has, the robot can be seen in figure 3 below.

FIGURE 3: *The social robot used in the stretching experiment showing a stretching move to a user*[3]

Toyama et al. [67] propose the use of two social robots to assist in a persons self coaching of sports training. One robot,the target robot, is used to reproduce the movements made by the user while the other robot, the reference robot, mimics the movements of a pro athlete performing these same movements. The idea was that the user could see the difference between both robots and adapt their own movements to get them to be more accurate to the ones made by a professional athlete. The experiments were performed with as sport volleyball, a mostly upper body sport. The self-coaching approach was unable to be the leading factor of skill. Although the fundamentals are there for a useful system. A cause for this lack of improvement could be the difficulty with which the movement of the target robot can be changed. The target robots movements can only be changed after the system has been stopped.

Avioz-Sarig et al.[4] developed two personal training systems for elderly using a robot, NAO and Poppy, and a RGB-D camera which monitored the users performance while they did certain exercises. The exercises performed were strength training exercises such as or combination of; bending elbows, raising arms, raising arms forward, raising arms separately to the side or horizontally, and turning hands. Both robots gave auditory and visual (facial movement) feedback based on how the users were replicating the movement. In figure 4 the robots can be seen demonstrating the movements the users have to replicate. Users reported they intended to use the robot as an exercise coach. However, more users (80.6%) of the only auditory feedback group said so than in the auditory and visual feedback group (72.7%). Additionally, continuous feedback throughout the exercises was preferred over discrete feedback at the end of an exercise . Lastly, participants who enjoyed the activity were more likely to say they would like to use the robot again. This indicates that instant feedback is something which is valued by users as well as enjoyment of interaction.

Figure 4: *The robots demonstrating movements to the users, in the top image poppy is demonstrating movement while in the image below NAO is demonstrating a movement*[4]

From these robots currently in use some lessons can be learned. Most important is the ease of use; from Toyama et al. [67] it can be seen that the robot should be intuitive and direct in its feedback. Avioz-Sarig et al.[4] agree with this as their participants prefer instant feedback over staggered feedback. From said research another take away is the importance of enjoyed activity. Lastly, the users should not feel like the robot is limiting their progress as might have been the case for Tozadore et al. [3] as the limitted range of motion could have held the users back from complete stretches.

2.2.3 The acceptance of Social robots

There are a few aspects to when and how a social robot is accepted by its users. Fong et al. [20] supply that there are multiple factors which influence a persons acceptance of a SAR. These factors are; the robots embodiment, a persons knowledge of said robot, and their previous interactions with a robot. Additionally, users opinion of the robot was effected by the robots face ;rounder '*robot like*' features and facial expression indicative of intrigue and attention, made users more accepting of the robots. Bishop et al. [23] add that previous interaction negatively affects a users acceptance of a SAR. Moreover, they state that the tone and manner the robot takes on; cheerful, neutral, or negative, also affects the users acceptance of a SAR. A cheerful robot seems childlike, a neutral one not helpful while a negative tone seems the most useful. An option to have the users accept the cheerful one is by supplying a guide. However, Naneva et al. [68] state that previous interaction is not of importance in the initial acceptance of SARs. They say that the overall acceptance of social robots is there although apprehensive. Fasola and Matarić [22] agree with Fong et al. [20] on the embodiment of the robot leading to acceptance. They found the physical embodiment of the robot yielded a stronger acceptance than a virtual robot did. From this it can be concluded that social robots are accepted conditionally; they are physically there, they are novel to the user (or with a guide), and they are verbally and physically expressive.

Aside from these factors influencing acceptance SARs have other problems which might affect their acceptance in the world. Due to the nature of these robots ethical concerns are at play. Prescott and Robillard [69] raise the concern that as these are just robots doing socially assistive work they can and should not replace people doing said work. They assert that as these robots can not feel they are intrinsically deceptive in their social interactions, as their expressions and concern are not their own but just code. Additionally, Fong et al. [20] supply that this coded dialogue can lead to stereotyping by the user and have them attribute values and qualities to the robot which they do not have. This can affect the users acceptance of these robots. Hence these robots should not be seen as a stand-alone solution, but rather a supplement to already existing courses of treatment.

2.2.4 Limitations

Of course the robot must also be able to interpret a persons nonverbal communication. It has to be able to interpret a persons affective and mental state, which as off now is not often taken into account in analysis of a persons state by the robot. However, Teeters et al. have developed a system which combines facial expressions and physiological systems to recognize a persons emotional state [70]. Duric et al. apply a model of embodied cognition which maps in detail a users affective state [71]. However, no such modules have been applied to social robots yet [72].

In addition to technical limitations there are more limitations, such as ethical and monetary. These robots are not capable of being a self-sufficient treatment course, a health-care-professional is needed to guide the treatment course. Additionally, these social robots are expensive and hence inaccessible to people with limited funds. These robots should thus be a temporary addition to a persons care. Although not a limitation a way to ensure the robots effectiveness is lasting techniques called *behaviour change techniques (BCT)* can be applied. Michie et al. [73] supply that behaviour change interventions, consisting of BCTs, are sets of activities applied together to change a behaviour or pattern exhibited by a person.

2.3 Behaviour change techniques

A source which provides a plethora of BCTs is the BCT Taxonomy[74], this taxonomy was developed by Michie et al. [75] it divides 93 BCTs into 19 different categories describing the nature of said BCTs. It is a tool which is commonly used by research designers and has been used to form an international standard of behaviour change techniques. Gilchrist et al. [76] have implemented this taxonomy in their rapid review in which they investigated the application of BCTs in physical activity programs for elderly. They found that a few of these 93 BCTs were commonly used: "action planning", " instructions on how to perform a behaviour", "graded tasks", "demonstration of behaviour", and "behavioural practice/rehearsal". Interventions which applied any of these commonly used BCTs also yielded powerfully positive results on both physical and social outcomes. Arnautovska et al. [77], who performed interviews with elderly to ask about their preferred method of motivation for activity, corroborate their results partly, they agree that both autonomy support and instruction to perform the behaviour is of importance. They also suggest that face to face delivery of said BCT is of importance.

3 Methods and techniques

The main goal of this project is to design, create, and implement a social robot to help patients with knee osteoarthritis manage their symptoms. To start this process first a plan or method needs to be laid out. To determine the Social robots capabilities, or rather requirements, a design tool can be used. One such tool is the MoSCoW method (3.2). Additionally, within the creative technology (CreaTe) program there is a known iterative design process which can be used. This process is called the Creative technology design process (3.4).

3.1 Personas

Developing Personas which are representative of the end users can help in the development of better ideas during brainstorming. It can help the developer step outside of their own experience and keep closer mind to their target group. Hence it helps to keep track of the needs of end users and is thus an easy way to ensure representation of the users in the final product [78].

3.2 MoSCoW method

The moSCoW method describes a line of ideation which entails requirement prioritization. It is used to engage stake holders in the design process in a collaborative manner.

Mo - Must have the requirements the project needs to have, without these the project is incomplete and has failed.

S - Should have a feature which is important to the project but not required for its success. These are a necessity and of high value for users and stake holders.

Co - Could have this group is non-priority, these are desired aspects of the design but they are not as important as the **should have** or **Must have** group.

W - Won't have A requirement which will not be implemented in the current project or the design there of.

These requirements are all of the same importance within their group. However, the groups are ranked on importance, going from top to bottom for most to least important [79]. By involving the stakeholders, the project will be as close to desired as possible. These stakeholders might add a new perspective which the developer of the project itself might not have thought of.

3.3 Attrakdiff questionnaire

The attrakdiff questionaire has been widely used to review user experience [80],[81]. According to Diaz-Oreiro et al. [82] it is even one of the most applied user-experience evaluation tools out there. The Attrakdiff questionnaire provides insight into both pragmatic quality (PQ) and hedonic quality (HQ) which then are combined to inform the overall attractiveness (ATT) of the product. The hedonic quality is further divided into hedonic quality-identity (HQ-I) and hedonic quality-stimulation (HQ-S) which then leads to four points of evaluation. These four points can be explained as follows:

PQ: which measures usability, efficiency, and effectiveness of the tested product.

HQ-I: which measures emotional reaction and a persons perception of the products alignment with their identity.

HQ-S: which measures emotional reaction and a persons perceived stimulation in the form of newness, creativity, excitement, and captivation of the product.

ATT: describes the overall value of a product for the user.

As the Attrakdiff questionnaire focuses on multiple facets of user experience it allows for more complete insight into the product. The questionnaire is best applied to a high-fidelity prototype to give the most insight into user perception of said prototype.

3.4 Creative technology design process

The creative technology design process, makes use of pre-existing design models. These models are divergence and convergence Models and spiral models. Divergence and convergence is commonly used, in that often first the design space is opened. The problem is approached from many varying perspectives, difference in culture and background can add to the development of innovative solutions. The convergence phase of this process is meant for pruning, its a gradual process based on design requirements (see MoSCoW method 3.2) and the designers experience. In the CreaTe design process this divergence and convergence is integrated into the ideation, specification, and realisation phases.

Spiral models are based on the idea that design is an iterative process, all the steps and questions are interconnected and hence the preceding phases of the process. Although, Mader and Eggink[5] agree that this spiral model is true and important in the design process they believe that a more structured model is more effective. This approach is aimed towards beginners in design who require just a bit more guidance. This design process they suggest can be seen in figure 5.

3.4.1 Ideation phase

The process starts with a design question. In creative technology, technology is used in the form of tinkering to build upon existing solutions, to find a novel solution. An assistive tool to the creative process is related work, which is integrated into multiple phases of the creative design process, as well as input of potential stakeholders.

In this project Personas (3.1) are used to form a basis for ideation, then the MoSCoW method(3.2) was used to form requirements against which the ideas could be bench marked. These ideas were then bench marked (see figure9) and further developed into four sub categories. Further ideation ensued in the form of different execution of these four categories. Three final ideas were decided. Lastly expert-semi-structured interviews were performed to discuss and decide the preferred idea(s).

3.4.2 Specification phase

characteristic to this phase is that rapid fire prototyping and testing is used for design exploration. The (possible) users provide input on the functionality of the prototypes which is then used to adjust the prototype or to develop an entirely new one. Due to the human centred design process the prototypes are reduced to far less functionalities which are responsible for certain experiences than the eventual product will have.

In this project the MoSCoW method was used to decide and prioritize requirements for the project. BCTs used in the project were listed and their application elaborated upon. The interaction the user has with the robot was decided and represented using a flow diagram. The specific types of exercise to be implemented and elaborated upon. Lastly, the achievement of the final concept through prototyping was expanded upon, by demonstrating the iterations the robot went through.

3.4.3 Realisation phase

When a product specification is reached the realisation phase can commence. First decomposition of the specification can be applied, e.g. what are the components needed for this project which or what type of these components will allow for the realisation of the design requirements.

For this project the prototyping of the specification phase comes to fruition in the form of a high-fidelity prototype. For this three features had to be developed, health dialogue, guided yoga, and exercise coaching. For this multiple platforms (choregraph and python) were used. The development of these features happened simultaneously.

3.4.4 Evaluation phase

This phase could entail a multitude of aspects. Actual testing of the functionality of the product is often done in the phase prior but might be done here. User testing might be used to evaluate the satisfaction of the design requirements decided in the ideation phase. Related work might be used for comparison and to place the product in the context of current works. Lastly, reflection upon academic and personal progress can be performed to review the designers own standards and assumptions within the design process.

For this project evaluation was done in two ways, through user testing and through consideration of requirements. During the user testing the test focused on user experience and usability, of the prototype. This was tested through a think aloud session, this is where the tester performs tasks and is asked to say what they think about the prototype aloud, the attrakdiff survey (see section 3.3), and a semi structured interview. The semi structured interviews allow for elaboration upon the testers experience of the prototype.

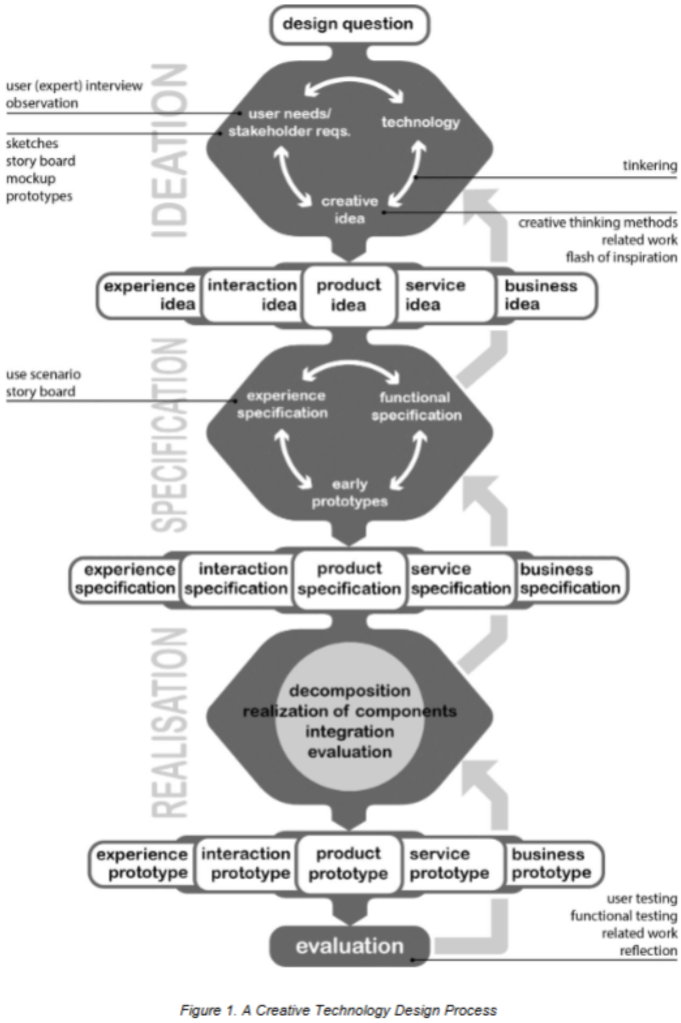


FIGURE 5: *The creative technology design process* [5]

4 Ideation

4.1 Personas

Developing Personas which are representative of the end users can help in the development of better ideas during brainstorming. It helps to keep track of the needs of end users and is thus an easy way to ensure representation of the users in the final product. For this project the following three personas have been developed. These personas can be seen in figures 6,7,8.

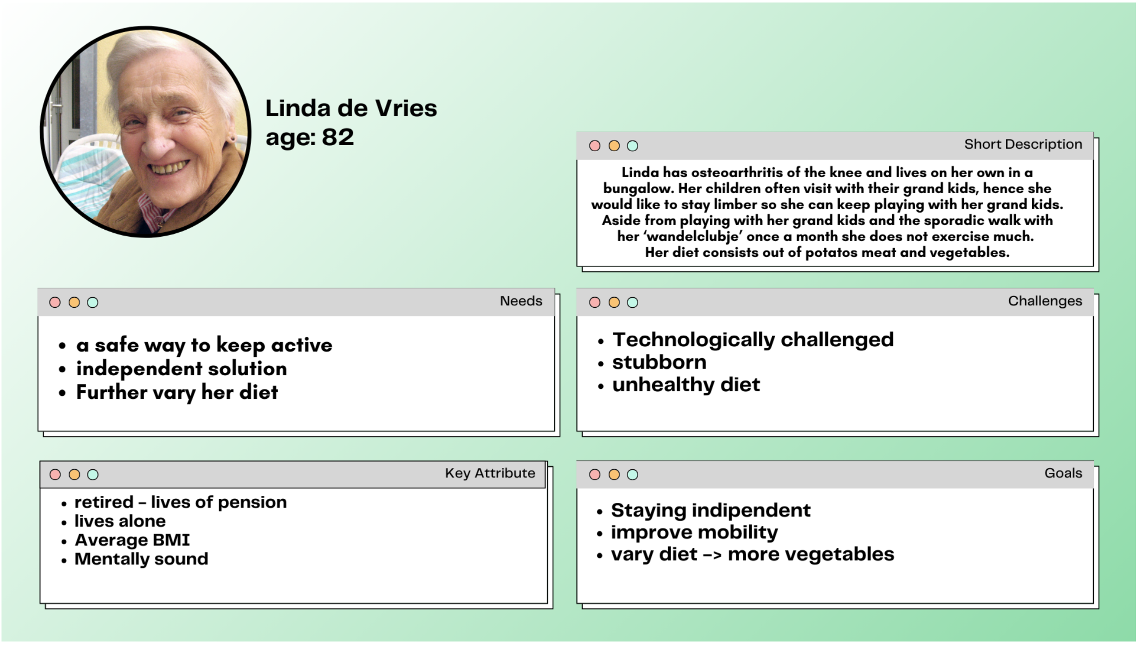


FIGURE 6: *Persona 1*

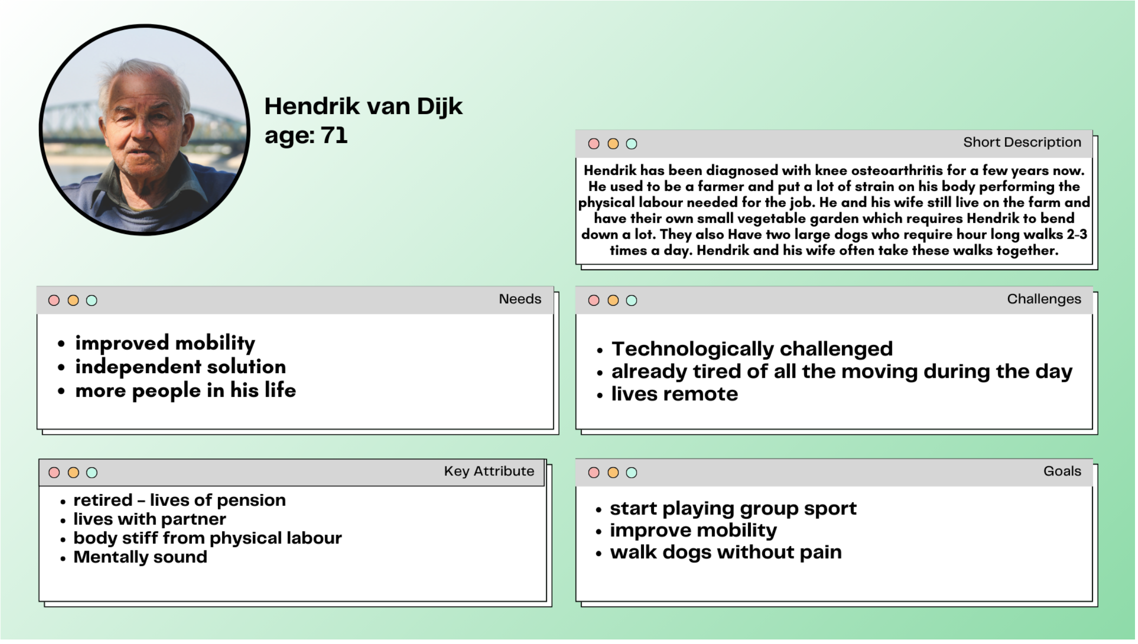


Figure 7: *Persona 2*

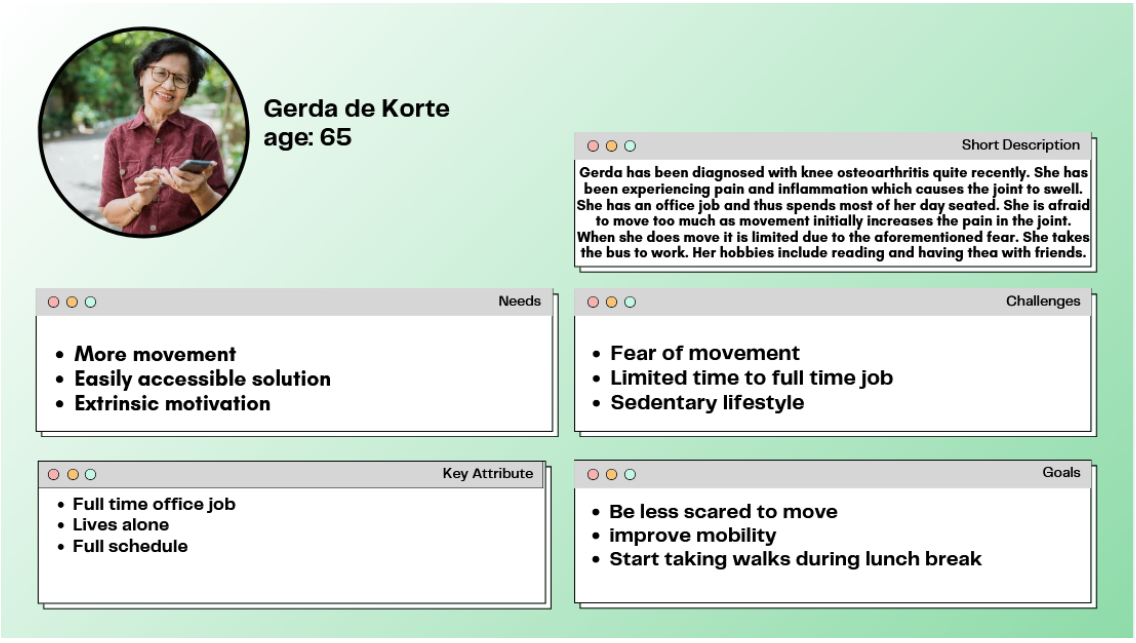


Figure 8: *Persona 3*

From these personas some key-points should be considered, some of these points have been discussed in the background research 2. The solution should be easy to use to everybody, this means there should be a limited to none learning curve. The solution should also be usable independently as these people might live independently it is important to make sure they can use it without assistance. Additionally, the solution should offer some form of support such that the users feel supported and motivated to use the robot. The solution also has to be short in its use sessions as the users might have limited interest in performing exercises with it if it takes too long. Lastly, the solution should explain decision making to make the users understand and at ease when performing the movements.

4.2 Divergent brainstorming

As stated in the method ideation phase 3.4.1, divergence for design is the first step in the process hence varying solutions were though of as a basis for the prototype. All the solution concepts are divided into categories by a letter system where A is non-robot related, B is lifestyle/habit change related, C is exercise regiment related, and D is health-care related. The numbering of the concepts is random and not related to either priority or which one was though of first. The brainstorming was done on post-it notes and then recorded in this project.

4.2.1 Non-robot solutions

To keep the brainstorming as wide as possible, non-robot related solutions were also considered. These solutions are as follows:

1A. Automatic yoga mat which roles out when its time for the user to exercise. Glows through a spectrum of red and green to indicate the accuracy of the exercise being performed.

2A. A couch which measures the way a user sits down/ stands up. The couch vibrates to indicate if the movement is indicative of harm to the knee.

3A. A treadmill which measures gait and more importantly the force applied when the foot is set down to find the force applied to the knee. provides feedback through a video or LEDs.

4A. Knee brace which measures oxygen level, knee flexion, and heart rate.

5A. Implementation of VR/AR to make daily movement a game, encouraging users to move daily.

4.2.2 Lifestyle change / Habit formation related

Concepts related to lifestyle change / Habit formation are discussed here.

1B. The robot starts flashing a light and sounding the alarm every time the user needs to start doing a certain task.

2B. The robot emotes every time a required task is performed when needed.

3B. The robot starts looking for the user when a certain task needs to be performed and takes them back to the allocated spot determined in their environment to perform said task.

4B. The robot keeps track of how often the exercises are performed in time, or how often the exercises are done as they might be performed more often than baseline requires.

5B. Once the user has performed an exercise routine an x number of times with the guidance of the robot, the robot does not perform the exercises with them but rather watches to see the users performance. If they do well that specific routine is only watched and provided feedback on. If they do not perform so well the robot keeps teaching them the routine for another x number of times to repeat the process.

6B. The robot helps in forming a SWOT analysis to help the user on their way in their habit-change journey.

7B. Users can set daily goals to challenge themselves and ensure the regular exercise becomes a habit for them.

8B. Re-use previous exercises in certain orders to form a routine, include newer exercises once older once have been adjusted to.

9B. A day of exercise can be skipped as long as the user provides a reason for skipping that day. Valid options such as pain of course are reasonable. These reasons for skipping a day are tracked and can be sent to a doctor if wanted.

10B. Suggest planning an appointment with the users gp/ health coach to check on how the formation of the habit is going, or how the users health is doing.

4.2.3 Exercise regiment related

1C. The robot gives a thumbs up every time an exercise is completed correctly.

2C. The user puts on music, the robot interprets this music, e.g. genre and bpm, and adjusts the exercise plan of the day to this music. Adjust the rate of exercise to the tempo of the music or have the user perform a movement on every fourth beat.

3C. Group exercise option, the user brings in another person, or other persons, the robot adjusts its exercises based on the group. Still focused on the single user.

4C. The robot asks about pain levels and sleep cycle completion, is it okay or bad for the day? Then it adjusts the exercise intensity based on this input.

5C. The robot asks the user about which exercises they enjoy or do not enjoy. Based on this it adjusts the exercise program.

6C. The robot does a trick every time an exercise routine is performed successfully.

7C. Save a users preferred movements, and work these in more often than non-preferred movements/exercises.

8C. The user can show/teach the robot moves they themselves like, so these moves can be incorporated into the exercise regiment.

9C. The robot can be taken on a bike ride with you, put in your basket for example and it helps as a motivational coach.

10C. The robot provides help when it keeps detecting frustration in its user during exercise regiments.

11C. Movements which are disliked by the user can be skipped.

12C. When certain movements have been refused other options are provided to make sure the exercise protocol still reaches the requirements/goals set for that day.

4.2.4 Health-care related

1D. The heartbeat and oxygen levels of the user are tracked. To measure their activity level and to check if they are doing well. Once either of these are outside of healthy boundaries the robot enforces a break. For this first resting heart rate and oxygen level need to be recorded or provided to the robot.

2D. The robot asks about sleep-quality every day. Keeps track of the trend and warns for potential pain flare when the sleep-quality is poor for a week or longer.

3D. The robot suggest healthy meals, or certain meal adjustments to make said meals healthier.

4D. The robot asks about mental well-being. If it is concerning a call to the users general practitioner could be made to make sure the user is checked upon by an actual person.

5D. The robot aids the user in cooking, suggests healthy options. For example to adjust the salt in take to a certain amount.

6D. Keeps track of what has been had for dinner and suggests varied options to keep the users diet varied.

7D. Sends collected data to gp.

8D. Can be asked or talked to about mental health, if situation calls for it mental-health professional is contacted.

4.2.5 Miscellaneous

1E. Provide separate options for introductory training/course. Health-care professionals get a course on how to implement the robot. The users get a course on the robots interaction options, e.g. this is how you start the robot. To ensure both the user and their healthcare team are aware of how the robot works and what it can help with.

2E. Provide an option for the collected data to be removed after every session. First an explanation on the use of the data within the robot is provided.

3E. When the robot is malfunctioning or requires a service, it suggests to update itself and does so, or it suggests its hardware needs to be checked so service for which can be provided.

4E. Adding wheels to the robot to increase its mobility, maybe the user can take the bot on walks with them.

5E. Multiple types of voices to adjust to preference of user.

6E. In case the robot keeps frustrating the user in its errors it asks to schedule an appointment with a robot professional and plans this appointment on its own.

7E. make the exercise regiment a challenge and allow for a comparison to friends to add a competitive motivation.

8E. project tetris on the ground to make the user play the game while they perform their movements.

4.3 Convergent brainstorming

To end up with a final idea convergent brainstorming is needed. The evaluation of these ideas is then represented in a chart in section 4.3.1. First, ranked requirements are set for the project then based on these requirements a chart of feasibility V.S. meeting of a requirement is made. This chart can be seen in figure 9.

4.3.1 MoSCoW method application

Based on the following preliminary requirements the previous ideas of section 4.2 can be evaluated.

Mo - Must have the requirements the project needs to have, without these the project is incomplete and has failed.

- The human robot interaction must be intuitive.
- The robot must apply BCTs 2.3

S - Should have a feature which is important to the project but not required for its success. These are a necessity and of high value for users and stake holders.

- The robot should offer different types of exercise.
- The robot should be fun to use.

Co - Could have this group is non-priority, these are desired aspects of the design but they are not as important as the **should have** or **Must have** group.

- The robot could have multiple types of voices.
- The robot could help with the users diet.

W - Won't have A requirement which will not be implemented in the current project or the design there of.

Based on these requirements a chart of feasibility vs. requirement achievement was made. Feasibility in this context means, is it possible to make this into a social robot, can this be achieved within time constraint, and is it possible within budget? Meeting of (a) requirement means, if the idea (sort of) addresses at least one of the requirements set using the MoSCoW method. This chart, see figure 9, allows for thorough comparison of the ideas.

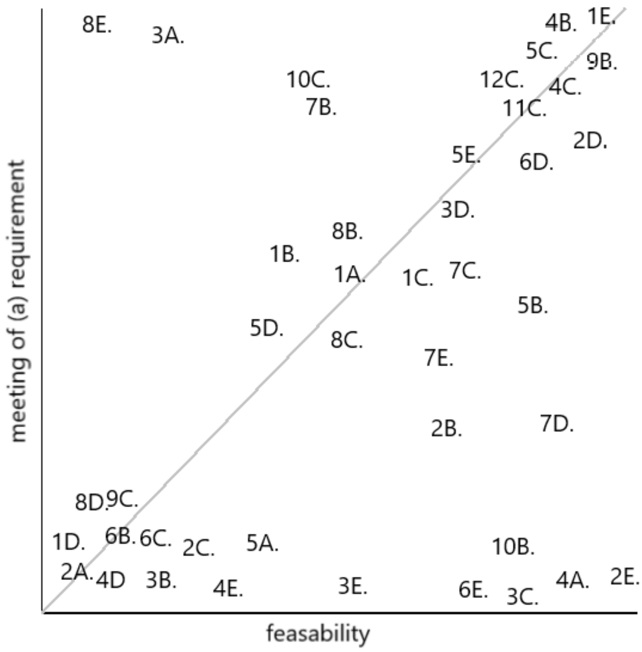


FIGURE 9: *A plot of the brainstormed ideas, based on feasibility and the requirements being met.*

Based on the requirements and the chart, see figure 9, some decisions have been made as to which ideas are suitable to continue with. All ideas which scored low on both feasibility and meeting of requirement were excluded. Next the ideas scoring low on either feasibility or meeting of requirement were excluded as it is important that an idea is both feasible and meeting a requirement. Then the ideas around the center were reconsidered. Although these ideas are not ideal some might be useful in further implementation, or could be developed further, and thus were also taken into consideration during the convergence part of the brainstorming. The ideas which scored well on both feasibility and meeting of requirement were automatically taken into the convergence part of ideation. Only 11C. was excluded as it was almost a duplicate of 9B.. The following ideas will be continued with:

4B. The robot keeps track of how often the exercises are performed in time, or how often the exercises are done as they might be performed more often than baseline requires.

5B. Once the user has performed an exercise routine an x number of times with the guidance of the robot, the robot does not perform the exercises with them but rather watches to see the users performance. If they do well that specific routine is only watched and provided feedback on. If they do not perform so well the robot keeps teaching them the routine for another x number of times to repeat the process.

8B. Re-use previous exercises in certain orders to form a routine, include newer exercises once older once have been adjusted to.

9B. A day of exercise can be skipped as long as the user provides a reason for skipping that day. Valid options such as pain of course are reasonable. These reasons for skipping a day are tracked and can be sent to a doctor if wanted.

4C. The robot asks about pain levels and sleep cycle completion, is it okay or bad for the day? Then it adjusts the exercise intensity based on this input.

5C. The robot asks the user about which exercises they enjoy or do not enjoy. Based on this it adjusts the exercise program.

7C. Save a users preferred movements, and work these in more often than non-preferred movements/exercises.

10C. The robot provides help when it keeps detecting frustration in its user during exercise regiments.

12C. When certain movements have been refused other options are provided to make sure the exercise protocol still reaches the requirements/goals set for that day.

2D. The robot asks about sleep-quality every day. Keeps track of the trend and warns for potential pain flare when the sleep-quality is poor for a week or longer.

1E. Provide separate options for introductory training/course. Health-care professionals get a course on how to implement the robot. The users get a course on the robots interaction options, e.g. this is how you start the robot.

2E. Provide an option for the collected data to be removed after every session. First an explanation on the use of the data within the robot is provided.

5E. Multiple types of voices to adjust to preference of user.

These ideas can be further integrated to form comprehensive features of the robot. Ideas 4B, 4C, 5C, 7C, 2D, and 12E are combined to make the following feature: The robot tracks a multitude of aspects such as, rate of exercise performance, quality of exercise performance, exercise enjoyment, frequency of (non) performance of exercises, sleep and pain levels, and exercises preference. The tracking, and importance of doing so, of these aspects is communicated and explained to the user. In case the user indicates being uncomfortable with certain, or all, data being stored the robot should remove this information from its drive. This idea will subsequently be called 1F.

Based on not only these tracked aspects, but also specific user input, the robot can and should make adjustments to the exercise plan. Hence the following feature, based on ideas 9B, 4C, 5C, 7C, and 12C can be implemented. The adjustment of the exercise program, the adjustment could be in; weather or not the exercise(s) is executed, the intensity of the exercise, the duration of the exercise regiment, and what exercise movements are used. This idea will subsequently be called 2F.

As mentioned in ... social robots should not be used as a permanent solution but rather an addition to an already standing health-care plan. Hence, the robot must aid in making these exercises a habit. Based on ideas 4B, 5B, 8B, 5C, and 10C healthy habits based in exercise can be developed by the users. The users in the first few weeks of interacting with the robot are shown exercise regiments/steps, these are in a specific order in such a way that the user can more easily remember these steps. Once the frequency of necessary constructive feedback is below a certain threshold the robot suggests that the user tries the exercise routine on their own next time. The user can then accept or refuse this proposition, if accepted in the next training/coaching the robot no longer demonstrates the movements. The user performs the routine on their own while the robot watches, during this routine the robot provides encouragement and feedback where necessary. If the user struggles too much then the robot will go back to demonstrating the correct movements/sequence of movements until the user is again deemed ready to perform on their own. If the exercise routine is performed well enough said routine is deemed complete and will henceforth only be watched by the robot, unless the user again goes below a certain threshold of performance. After successful completion of a routine a new exercise routine could be implemented. This idea will subsequently be called 3F.

Lastly ease of use is a feature which should be considered, hence idea 1E and 5E are integrated. The user should get a tutorial on how the robot can be used, and how it can be interacted with should be provided to the user. Additionally, the users health-care provider should be informed on how this robot can be implemented by them (the health-care provider) to ensure the robot is used optimally for their patient/user. To ease the user's contact with the social robot, the robot's voice type, intonation, and vocabulary could be adjusted. This idea will subsequently be called 4F.

These 4 facets to an idea were not satisfactory to a final idea hence some further brainstorming on the form in which they could be implemented was done. This led to a list of 'shells' that could implement the important facets of a social robot to manage KOA symptoms, the ones selected for further implementations have been highlighted with bold lettering, the ones not picked have an explanation as to why not:

- **The robot NAO 6** which would be capable of performing all features.
- A lamp, with mood lighting to indicate the performance of exercises, *this strays away from a social robot as it removes almost all forms of social interaction. The user has almost no way to communicate with the lamp.*
- An electric candle, *This has the same issues as the aforementioned lamp.*
- **An alarm clock with a microphone and speaker** would struggle with the exercise part of the ideas. However, would be capable of tracking and might give users more freedom in their exercise type.
- A decorative pot or something else ornamental with a speaker and microphone. *The lack of a face might make people feel weird about talking to the ornament, additionally only the addition of audio can be quite limiting for social interaction.*
- **A smart mirror**, might be capable of showing the exercises depending on what type it is. Would be capable of all other functions.

The introduction of these different forms in which the thought of ideas are expressed influences how these are executed. The robot might show a user an exercise while the smart watch would be unable to do so. Further demonstration of these differences is provided in the storyboards in section 4.3.2.

4.3.2 Storyboarding

Below is the depiction of the described facets and their integration into different shells is shown. Further explanation and considerations are discussed in accompaniment of the storyboards.

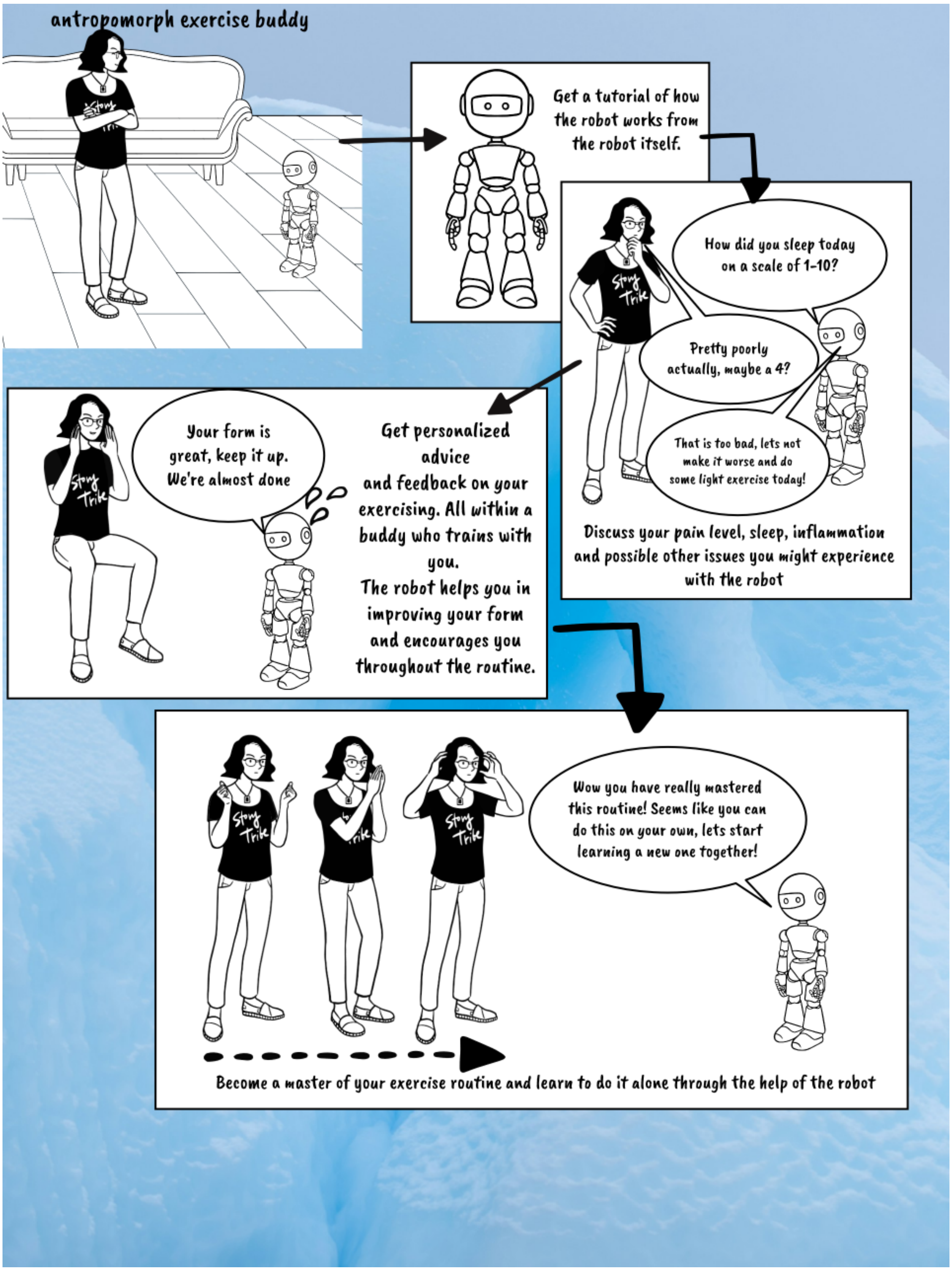


FIGURE 10: *The storyboard describing the implementation of the robot NAO 6 as a social robot.*

The robot provides an exercise buddy that helps a person to exercise and motivates them throughout. First, it provides a tutorial on its uses and ways it can be interacted with. The explanation the robot provides is not limited to this tutorial but can be provided throughout its use. The robot also asks the user about their physical well-being, this

includes pain, sleep length and quality, joint inflammation, and any other points the user might want to address. The robot then decides an appropriate exercise plan for the day which the user can follow, they are also allowed and encouraged to refuse exercise at any point. Lastly, the robot helps the user form a habit of exercising by training and testing the user's capability to perform an exercise routine on their own. This is done by the user demonstrating a practised routine and the subsequent evaluation of said routine by the robot. If the user performs well the routine is considered learned and otherwise more practice is encouraged. The robot NAO should be implemented for this as it has successfully implemented by Avoiz-Sarig et al. [4], NAO has the option to move its legs which is important in demonstrating movements for KOA patients.
People feel more motivated to perform exercises with another person there, the robot functions as this other person. Additionally, through the application of positive reinforcement the user gets more confident in their performance of the exercises and learns that exercising can lead to healthy management of KOA symptoms.

Some considerations for this idea are the following:

- The robots interface must be as intuitive as possible, it is important the robot is understood so that people are more likely to want to use said robot as discussed in section 2.2.2 and 4.1.

- The robot must provide instant feedback instead of delayed feedback as discussed by Toyama et al. and Avioz-Sarig et al.[67],[4] this is preferred when elderly use a social robot as an exercise coach.

- The robot will encourage the user to stay active and provide positive feedback throughout activity. As mentioned by [76] elderly people prefer a few BCTs when exercising, two of which are demonstration of behaviour and instructions on how to perform a behaviour. This can help them learn how to do these exercises on their own.

- The robot should be clear in its decision making, it might suggest a type of exercise based on the information provided to the user. It should clearly describe why this decision was made as to assure and make the user feel at ease. As discussed in section 4.1 people can be afraid of over exerting themselves and hurting themselves more by using their joints [15].

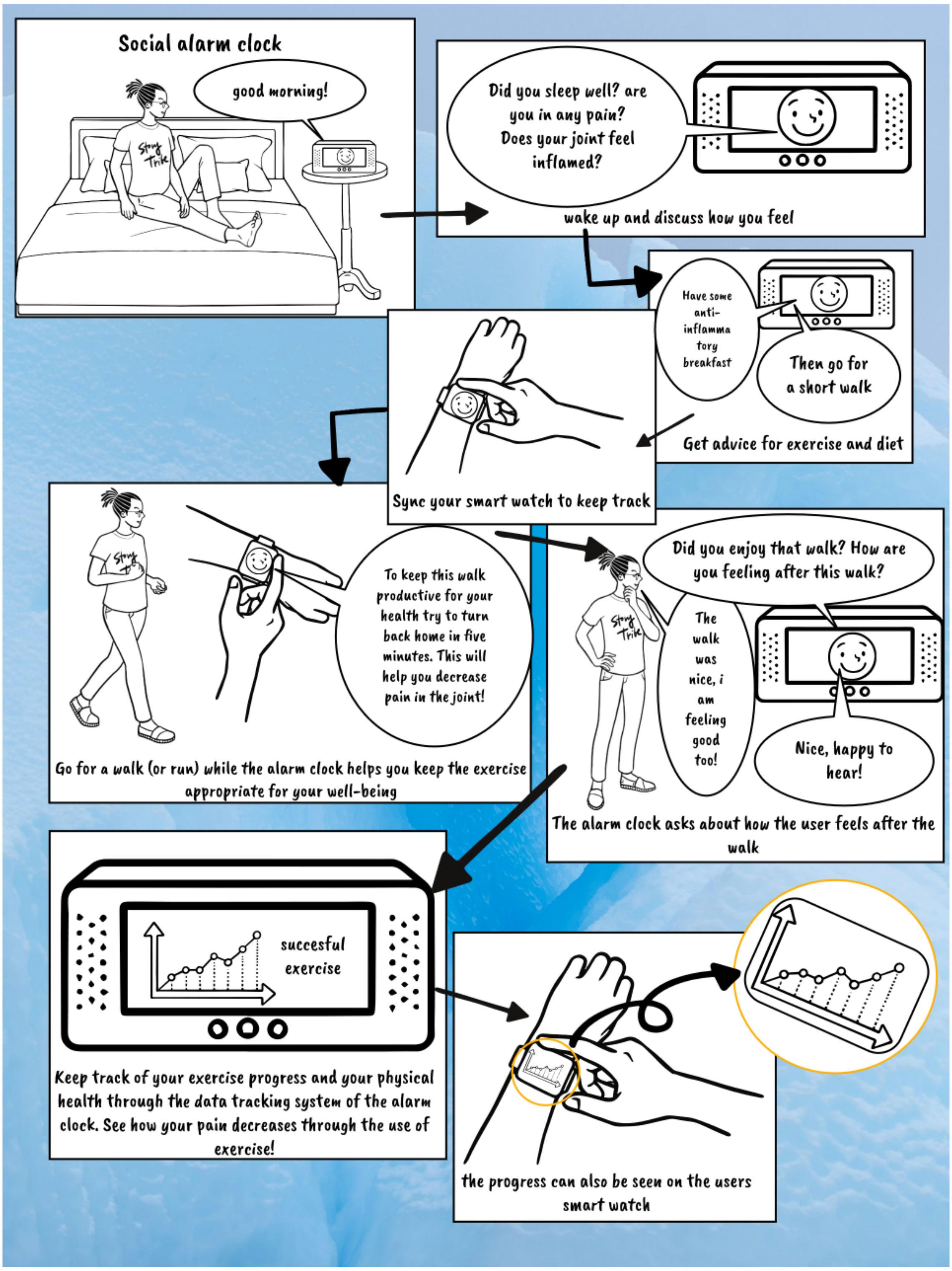


FIGURE 11: *The storyboard describing the implementation of an alarm clock in collaboration with a smart watch as a social robot.*

The alarm clock serves its user similarly to a personal assistant, specifically for exercise. It wakes the user up and asks them about their sleep and physical well-being. Based on this it recommends certain breakfasts and exercises to the user. The user may refuse or abide. After sinking their smartwatch the user can take the social (alarm) clock with them during exercise and throughout the day. On both the alarm clock and smartwatch they can see their progress and get advice on how long they should keep exercising. At the end of the day, they discuss how they felt with the alarm clock and they can see their progress on the alarm clock display.

The alarm clock provides a new sense of independence, it allows the user a lot of freedom in deciding their exercise and diet but also offers structured guidance for said exercise and diet. Through the tracking of the user's progress and encouraging feedback the user stays motivated to keep up with their exercises.
Some considerations for this alarm clock include:

- It must provide encouraging feedback in the smartwatch during the performance of exercise [76].
- The robot should be clear in its decision making, it might suggest a type of exercise based on the information provided to the user. It should clearly describe why this decision was made as to assure and make the user feel at ease. As discussed in section 4.1 people can be afraid of over exerting themselves and hurting themselves more by using their joints [15].
- The watch should not be a stand alone solution as this might isolate its users from the world [20].
- Users should be able to choose when they provide the clock information, maybe they prefer discussing their health after breakfast. However, this does take away the nutritional advice.
- Users should be able to shut-off/mute the smartwatch social actor when they do not want to use it, or hear feedback. As discussed in 4.1, the personas prefer a non intrusive solution which means the watch should be mutable. The users do not need constant input.

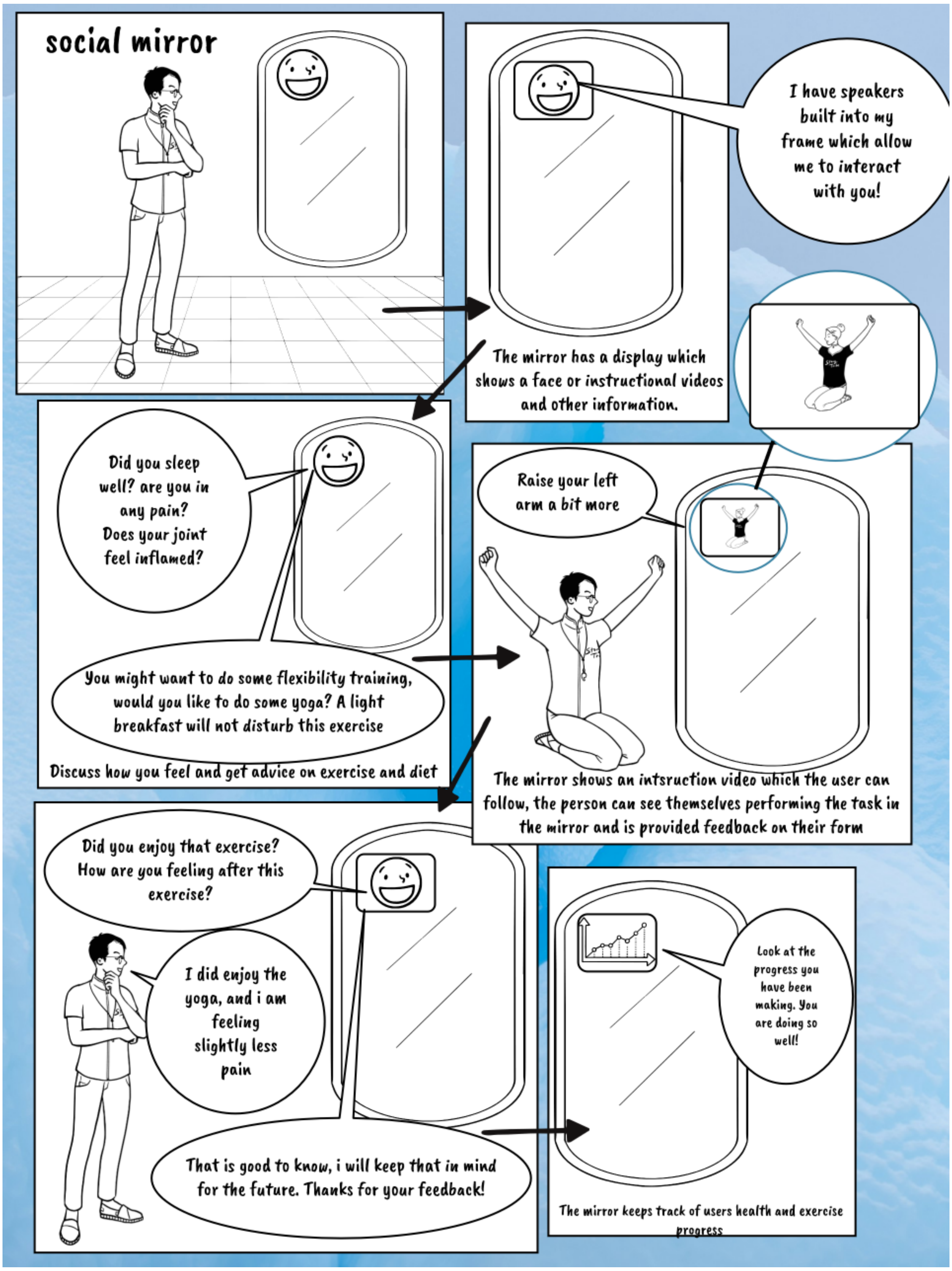


FIGURE 12: *The storyboard describing the implementation of a smart mirror as a social robot.*

The social mirror acts as a guide through exercise by asking the user about their physical well being and providing personalized advice based on that information. It suggests an exercise which can be done in front of the mirror such that the user can follow the mirrors video guidance. The mirror provides feedback on the users form and encourages them throughout the exercise. The user can see their performance in the mirror as they are doing the exercises. After the exercise the mirror asks the user how they now feel and provides a moment for feedback. The mirror stores both the wellbeing and exercise data to show the user their progress.

The reflective surface of the mirror provides the user with a way to self manage their exercise form with the help of feedback from the mirror. The instructional videos show the user how the exercises can be done serving as a personal coach which optimizes training.

Some considerations for this mirror are the following:

- The mirror must provide instant feedback instead of delayed feedback as discussed by Toyama et al. and Avioz-Sarig et al.[67],[4] this is preferred when elderly use a social robot as an exercise coach.

- The robot will encourage the user to stay active and provide positive feedback throughout activity. As mentioned by [76] elderly people prefer a few BCTs when exercising, two of which are demonstration of behaviour and instructions on how to perform a behaviour. This can help them learn how to do these exercises on their own.

- The character in the mirror must not pretend to feel emotion as this can cause a one sided emotional connection to form on the users part [69]. Which is deceptive, the mirror should avoid this.

- The robot should remind the user to exercise if it spots them, as a virtual robot is less effective in user acceptance than a physical robot [22]. The reminder of the need for exercise could motivate the user more bringing the virtual robot on par with a physical robot.

4.4 Final idea

Through the use of semi-structured expert interviews these previous four facets of an idea and the preferred shell are further developed into a specific solution. These interviews, in addition to previous brainstorming and background research, form the basis for the final idea. An expert interview with two experts was conducted. These experts have a background in physical therapy (PHD) and biomedical engineering (PHD) respectively. Both are working on the load project. During an interview, where the experts were interviewed simultaneously, questions relating to suitability, personal preference, and design changes/ additions were discussed. The exact questions asked can be read in A. Based on the answers and insights provided by the experts some conclusions could be drawn.

The three ideas, described in section 4.3.2 were presented to the experts and they quickly decided that concept 2 : social alarm clock was most useful in application. As the alarm clock, primarily the smart watch, allows for social assistance and activity tracking through out the day. This allows for a clearer picture of the overall activity of the user which in turn allows the social robot to provide the most complete and applicable advice to its user. This is something that both the robot and mirror do not allow as they are not capable of following the user throughout the day. However, a benefit that they do both provide is guided exercise which can be helpful for mobility training. Additionally, both experts expressed concerns relating to privacy with the mirror as it would most likely be positioned in a communal space, and as people often do not live alone another person might be tracked throughout the day. Hence this idea became the least favoured. The movability of the robot NAO 6 would make it ideal for guided exercise as the user can position the robot wherever they want them for the exercise coaching. Hence the experts suggested these ideas, the watch and the robot, can be incorporated. However, focus for the smart watch heavily went towards tracking activity throughout the day, other means of tracking such as inlay soles which could measure force exerted or a knee brace which could measure the angle the knee makes throughout the day were discussed. They agreed that this might be a large addition to develop with the limited time frame.

The final idea is as follows: The robot NAO 6 works in addition to an activity tracking system. The activity tracker collects data on a users activity throughout the day every day. The robot learns about the activity data in addition to the users current pain and inflammation level. Based on the activity, pain, and inflammation information the robot makes a recommendation to the user on safe movement for the day. It explains what parameters are used for this decision to guide the user to learn how they can decide for themselves when and how they should exercise. The robot then demonstrates these exercises (yoga), and encourages the user throughout the movement. Additionally, the robot functions as a coach for a separate set of exercises specifically developed for KOA pain symptom management. The considerations and where they stem from for this final idea are described in table 1.

Consideration	**reasoning**
The robots interface must be as intuitive as possible	Literature: It is important the robot is understood so that people are more likely to want to use said robot [2], as discussed in section 2.2.2 and 4.1.
The robot must provide instant feedback instead of delayed feedback	Literature: as discussed by Toyama et al. and Avioz-Sarig et al.[67],[4] this is preferred when elderly use a social robot as an exercise coach.
The robot will encourage the user to stay active and provide positive feedback throughout activity.	Literature: As mentioned by [76] elderly people prefer a few BCTs when exercising, two of which are demonstration of behaviour and instructions on how to perform a behaviour. This can help them learn how to do these exercises on their own.
The robot should be clear in its decision making, it might suggest a type of exercise based on the information provided to the user.	Literature: It should clearly describe why this decision was made as to assure and make the user feel at ease. As discussed in section 4.1 people can be afraid of over exerting themselves and hurting themselves more by using their joints [15].
The robot should implement some for activity data gathering	Expert interviews: Most information on activity can be found throughout the day by tracking activity level. A user is not only active when they are exercising with the robot.
The robot should implement mobility training (yoga)	Expert interviews: As the robot can not follow the user while they are walking or running etc. the robot can fill a gap by implementing a mobility training routine and helping the user improve said mobility.
The robot should respect the users privacy	Expert interviews: Although this was discussed specifically for the smart mirror it is applicable to the robot too. The robot should be movable and have an easy option to stop recording data from the user.

Table 1: Table demonstrating the considerations found throughout the ideation chapter

5 Specification

5.1 requirements

In section 4.3.1 preliminary requirements were made for ideation, now with the developed concept discussed in section 4.4 new requirements are set which allow for the further specification of the final idea. The goal for this social robot is for it to encourage and guide people through and to safe exercises such that they can improve their pain symptoms.

5.1.1 MoSCoW application for specification

Mo - Must have

- The robot must implement BCTs [74] . These BCTs and their implementation are discussed in table 2
- The robot must be intuitive in its use.
- The robot must have use sessions of 20 minutes or less.
- The robot must encourage daily exercise
- The robot must be safe to use, the user should never over exert themselves while using the robot.

S - Should have

- The robot should be enjoyable in its use.
- The robot should provide varied exercise options
- The robot should implement some for activity data gathering
- The robot should implement mobility training (yoga)
- The robot should respect the users privacy

Co - Could have

- The robot could function independently from other devices.
- The robot could speak multiple languages.

W - Won't have

- The robot will not deal with mental well-being.
- The robot will not join the user on walks or exercises outside of the set body weight and yoga exercises.
- The robot will not and should not act as a health-care provider.
- The robot will not save user data.

5.1.2 Behaviour change techniques and their implementation

In chapter 2 section 2.3 some BCTs to be implemented are discussed. These BCTs and how they are implemented within this project are described in table 2 below. Although the main aim of this robot is to help users safely execute certain exercises it is also intended to help them acquire and form a sustainable form of exercise routine. One of which they are capable of making their own informed decisions on how and when to perform these exercises.

1.4 Action planning	By going through and discussing the users physical well being, the robot helps the user to start a plan by suggesting a type of exercise for that day. The user can then decide for themselves when and where they do said exercise.
4.1 Instruction on how to perform the behaviour	During the exercise coaching the robot explains how to perform a set of exercises the correct way such that the user can execute those exercises. The exercise coaching exercises are further explained in section 5.3.1.
6.1 Demonstration of the behaviour	During the yoga routine the robot demonstrates certain yoga poses which the user then has to replicate. The yoga routine which the robots yoga routine is based on is further explained in section 5.3.2. Additionally after the health dialogue the robot explains why it makes the decision for the type of exercise to be done for that day, through this the robot demonstrates based on which factors it makes its decision on what exercise type the user should be performing.
8.1 Behavioural practice/rehearsal	Through repeated and long term use of the robot the user practices the exercises, the behaviour, many times.
8.7 Graded tasks	Through the guided exercise (coaching application of the robot) the user is prompted to increase the amount of repetitions of the exercises such that the exercise gets harder each time.

TABLE 2: *Table describing the application of the used BCTs within the project.*

5.2 Interaction

The robots main form of interaction is through speech and dialogue. To make speaking to the robot more pleasant for the users the addition of human like movement was implemented. As stated in section 2.2.3 people are more likely to accept a robot if they have a fuller speech and body language embodiment. The interaction with the robot starts upon start up, the robot is started and begins with an introduction and then explains the dialogue it and the user will be having. The robot asks a series of questions which the user then answers. Based on the answers the robot decides the best type of exercise to perform and explains this to the user. The user accepts and then together they perform the exercise. This flow is also depicted in a more concise way in figure 13 below.

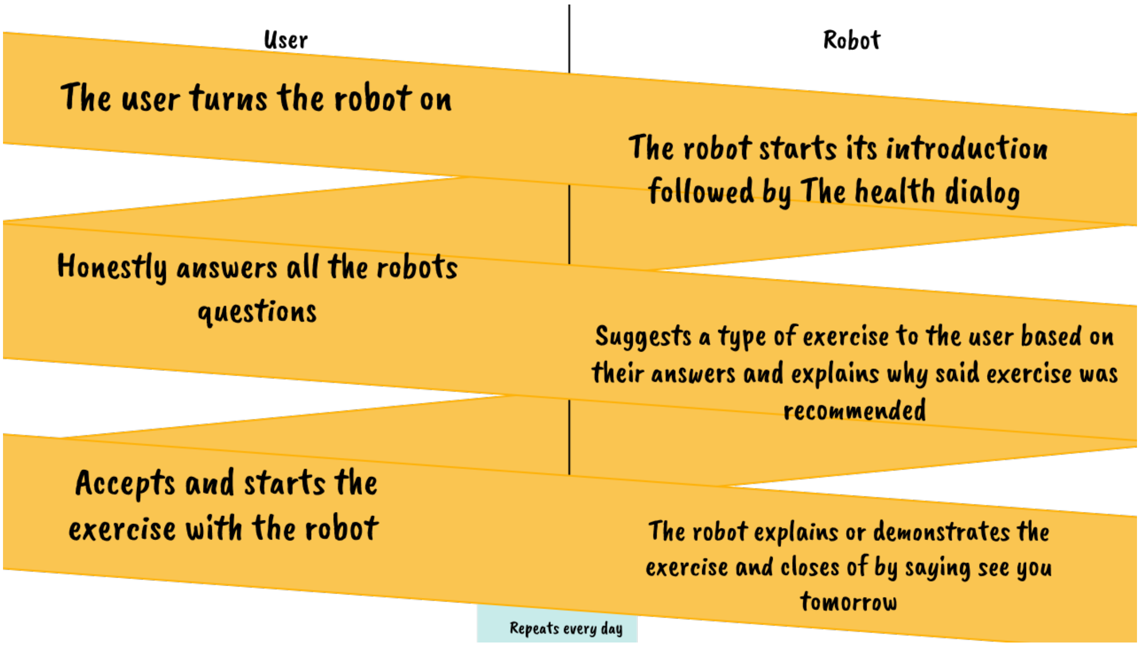


FIGURE 13: Interaction flow from user to robot

5.3 Exercises

As discussed in MoSCoW application for specification 5.1.1, the robot should implement certain BCTs further described in table 2. The application of these BCTs is done through implementation of certain exercises. These exercise are described in this section. As discussed in section 2.1.3 moderate exercise which focuses on building strength and increasing range of motion can help reduce pain in the arthritis affected knee. Hence for this project two types of exercise have been used. One of which are body weight exercises and the other is yoga. In section 5.3.1 the body weight exercises are explained, these focus on strength training. In section 5.3.2 the yoga routine is explained, this focuses on increasing range of motion.

5.3.1 Movements to be form monitored

Artrose Gezond, a dedicated information point for people with osteoarthritis founded by the Erasmus MC in Rotterdam, provides some suggestions for helpful exercises for multiple types of osteoarthritis. One of these is knee osteoarthritis, for which they recommend a few exercises that could be done throughout the week to alleviate a person's joint pain. These exercises are pictured below in figures 14,15, and 16. The full instruction sheet can be found in appendix B. The robot will describe these exercises to the user and track their movement to asses whether the users' form is appropriate and not hurting them.

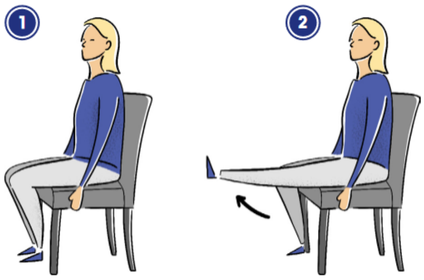


Figure 14: *The first seated exercise to help with pain in the knee joint*[6]

To perform the exercise the user is required to find a flat chair and to take a seat on it. The exercise starts by lifting one leg of the ground and bringing it up such that the knee has an angle close to 180 degrees. This position is held for 10 seconds after which the leg is slowly lowered again. The exercise then repeats for the other leg. When first starting this routine the aim is to repeat this exercise five times per leg and to gradually increase the frequency throughout the week such that it becomes easy to do said exercise 10-15 times each time.

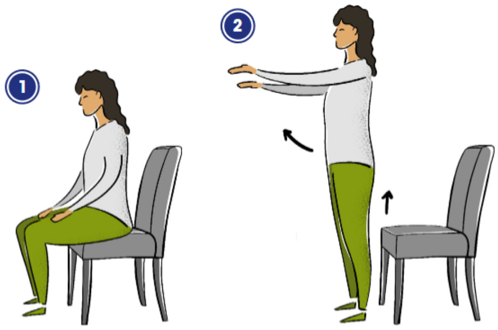


Figure 15: *The second seated exercise to help with pain in the knee joint*[6]

The second exercise is similar to a squat, this exercise, however, provides support through the addition of a chair. The user again sits on a flat chair, this time on the edge, they stretch out their arms and slowly rise up to a standing position. With their arms still stretched they sit down again. This exercise is repeated at least four more times, with a steady increase every time the exercise is performed such that the exercise can easily be performed 10-15 times at a time.

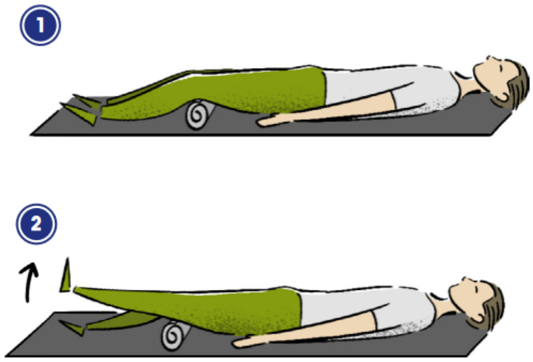


FIGURE 16: *The last suggested exercise which requires a person to lie flat on their backs*[6]

This exercise requires the user to lie flat on their back on the ground or a firm bed, with a rolled up towel (or yoga roller) under their knee. The user lifts up one leg, where their heel lifts up from the ground, and then holds this position for three seconds. They then slowly lower the leg, after which they repeat this exercise for their other leg. This exercise is repeated at least four more times, with a steady increase every time the exercise is performed such that the exercise can easily be performed 10-15 times at a time.

5.3.2 Yoga

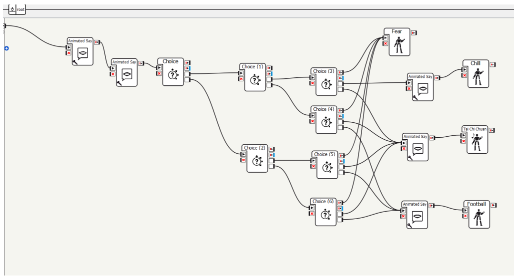
Aside from (body) weight training it is important to keep flexible as well, artrosegezond [6] suggests a multitude of flexibility training types, one of which is yoga. Due to its versatility yoga is widely applicable and customizable. The addition of a yoga routine in a persons weekly exercise routine could help them stay flexible and improve their lower extremity strength [83] and reduce their pain complaints. To lessen the impact on the joint a slow form of yoga, called vinyasa, is used to improve flexibility while breathing through the exercises, it uses a flow state to transition from movement to movement smoothly.
The robot will model such a flow state to the user while encouraging them to follow along. The Vinyasa flow state the robot will model is based on the sun salutation flow, an example of this flow is depicted in figure 17.

FIGURE 17: *Vinyasa yoga flow called Sun salutation, which the robots yoga flow demonstration will be based on [7].*

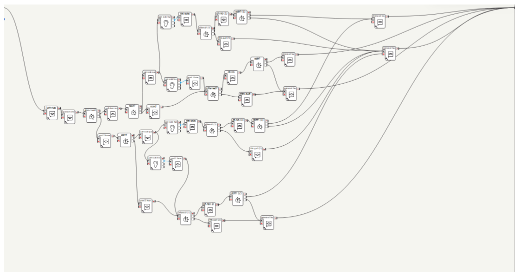
5.4 Final concept

The final concept was developed based on the requirements, which were set in the MoSCoW method (section 5.1.1), and further developed throughout this chapter. Three different functions were developed for the robot, as mentioned before in section 5.2 the interaction with the robot starts out with a dialogue about the persons health and is then followed by some form of exercise; yoga, body weight exercises, or a recommendation of a walk or swim. Considerations included making the interaction intuitive, enjoyable, and encouraging. For all the three different tasks the robot is developed to perform some prototyping was performed.

The health dialogue started out as only a series of yes or no questions, when it asked the user if their pain was above a five on a scale from one to ten, the user would answer with a number rating instead of a yes or no. Hence the integration of scale based answer options was needed. This resulted in a new questions path. This addition of scaling makes the interaction more intuitive satisfying said requirement. Additionally, as mentioned and described in table 2 BCT 6.1 is the demonstration of behaviour, to implement this in the health dialogue the addition of explanation on why a certain advice is given was added. Instead of the robot stating "based on your answers you should try body weight exercises" or other similar statements it says something like " As you rate your pain to be high on the pain scale and your joint is inflamed you should try doing some light body weight exercises".



((A)) First iteration of the health dialogue

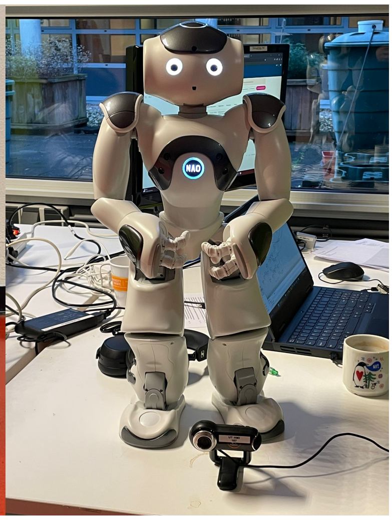


((B)) The second iteration of the health dialogue

FIGURE 18: *The first change from prototyping based on the pilot test*

For the exercise coach part of the robot the initial plan was to have the robot operate independently, meaning it uses no external devices. As NAO 6 has its own built-in cameras this seemed plausible. However, through the addition of movement to NAO, to make the robot more enjoyable as described in section 5.2, the users posture could not be analyzed fully or accurately. To ensure the users exercise form was at least adequate it was important that an unmoved camera was present. Hence an external camera was added to the prototype. This addition allowed the robot to fully analyse the movements made by the user as they are described in section 5.3.1.

((A)) NAO 6 on its own



((B)) NAO 6 with the addition of a camera in its intended position

FIGURE 19: *The second change from prototyping based on the requirement of safety*

Lastly the yoga routines initial intent was to execute the entirety of the sun salutation. However, due to the robots centre of gravity it was incapable of performing certain transitions in a way a person could safely follow along. Hence some adjustments were made such that the user could still improve their mobility through the assistance of the robot. The robot does not move to floor exercises but rather has a flow state through all the standing exercises. This state is illustrated in section 6.3.

6 Realisation

The realisation of a high-fidelity prototype consists out of four main parts for this project, as the prototype resulted in four main parts. These parts are;General set-up, Health dialogue, guided yoga routine, and supervised exercise routine. The general set-up explains how the robot needs to be initialized to work accurately, feature two and three were developed using choregraph 2.8.7.4. The supervised exercise routine was developed using python version 2.7 and 3.10.0.

6.1 General set-up

Before NAO 6 is ready to be used some minor set-up is required, said set-up can be described as follows. For the development of this project the robot NAO 6 has been used, this robot requires a stable internet connection. For this, a router had to be added to the hardware.This router was acquired from the interaction lab on the university of Twente campus. Then to change aspects of the robot a program called robot settings could be used. Within this program the robot could be rebooted and turned off, more importantly, the volume and language settings of the robot could be changed.

6.2 Health dialogue

Choregraph (v. 2.8.7.4) is a visual coding program developed specifically for the application to aldebaran robots. Within this program there are many built in features which allow for the coding of basic routines for the robot. The features used for the development of the health dialogue are depicted in figure 20.

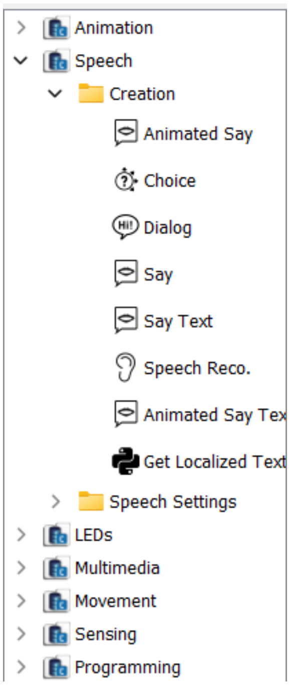


FIGURE 20: *The built in options for dialogue in the program Choregraph.*

A combination of Animated say, choice, and Speech Reco. was used to develop a sequence tree which leads to a decision on appropriate exercise based on the users responses. This sequence tree can be seen in figure 21. The robot starts out by standing up from the

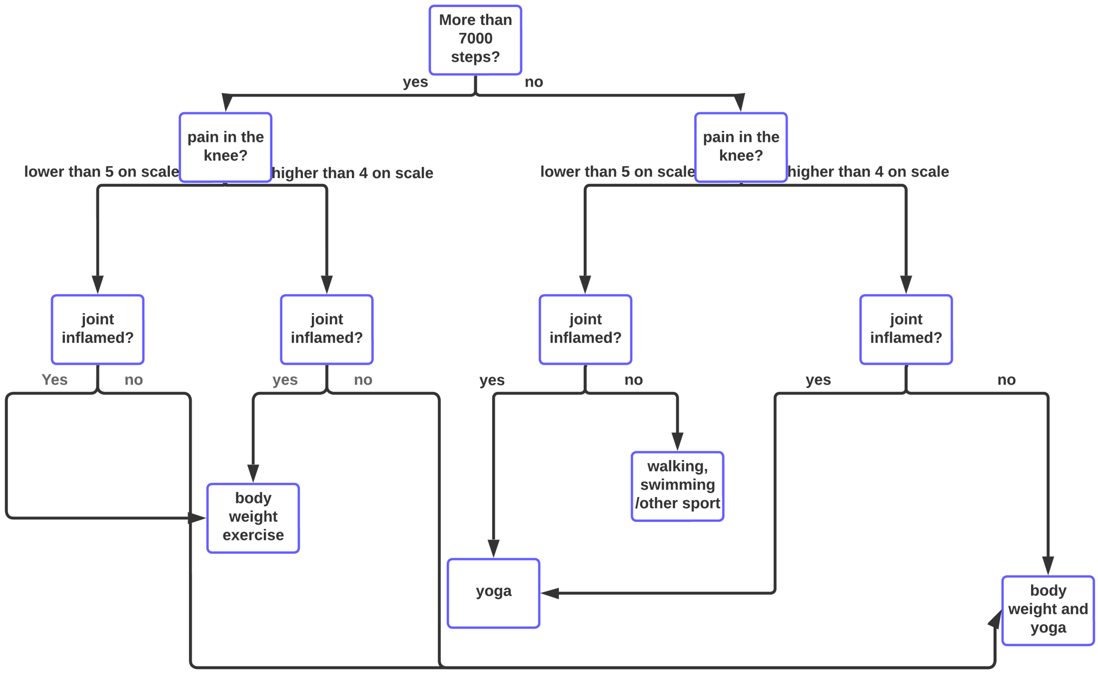


FIGURE 21: *A decision tree showing the variables on which the robot bases its decisions*

resting position described in section 6.1 and depicted in figure 21 the robot starts with a brief introduction of itself and the purpose of the health dialogue it and the user will be having. Then a series of yes or no questions relating to the users activity level, sleep, pain, and inflammation starts. The robot then decides based on the users answers what type of exercise is fit. The full dialogue can be found in appendix B (C).

6.3 Guided yoga routine

The guided yoga routine was developed in choregraph using the animation mode. This mode uses the touch sensors NAO has to move its limbs to certain positions. Using this mode NAO could be moved into certain positions such that they represent the postures described in section 5.4. This feature uses a two minute timeline to represent a longer yoga routine. While NAO is demonstrating the flow state yoga it also instructs the user on how to perform the exercises and encourages them to keep going. The full yoga routine can be seen in figure 22.

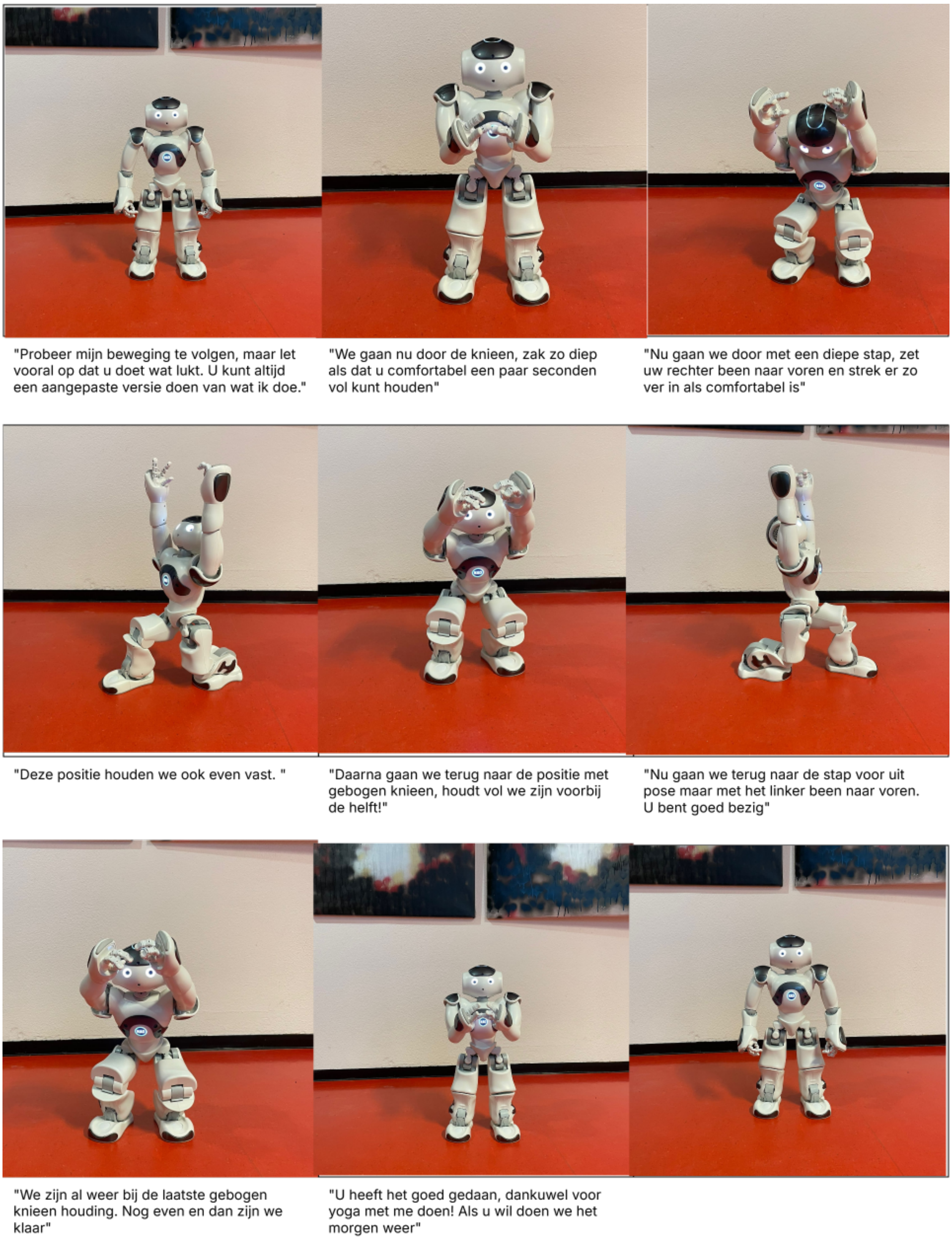


FIGURE 22: *The full yoga routine and the voice lines NAO says to support its users throughout performing the yoga.*

6.4 Supervised exercise routine

During the rapid prototyping phase initial discoveries on the usability of the robot were found, especially limitations to the capabilities of the robot. NAO 6 runs on a program called Naoqi for which the latest update was released in 2022. This means the software has become quite outdate in comparison to compatible software such as Python. The latest version of python with which the robot is compatible is Python 2.7.xx. This caused an issue for the development of the posture recognition as an infinite amount of bypassing to find and apply versions of libraries and plug-ins, which allow for posture recognition was needed. A solution to this was found in the addition of a separate python file using a newer version. As the robot had to say certain things once mistakes, position falter, or completion of an exercise was achieved it was important for there to be communication between the separate python versions.

6.4.1 Inter python communication

The communication between the separate python versions was facilitated through file writing, using file writing ensures that the two codes remain completely separate from each other. This separation is of importance as it avoids errors based in library versions. Although libraries for python 2.7.x have mostly fallen out of support it is still possible to use some of these libraries. Hence ensuring that the two files are completely separated through the implementation of virtual environments and file writing no library version errors can occur. Both python files, the one running NAOs embodiment and the one analysing the users posture, have a separate script which is capable of sending and receiving information to files.

Two files, local to the computer which runs both the posture analyser and robot software, are used for this communication: "Robot_writer" and "Camera_writer". As the names state "Robot_writer" is used by python 3.10 to write information to the robot while python 2.7 uses "Camera_writer" to write information to the camera. Separate files were chosen as the robot needs to perform certain tasks while the camera is still performing a task. Through sending information through separate files continuous working of both robot and camera is ensured. It is important that these files are continuously checked for changes as both the robot and camera should respond immediately to change.

In both python versions the libraries os and time are used. os is used to access information from the operating system such as the last time a file was updated. time can be used to add a delay to the frequency at which a task is performed. These are used in tandem to check if and when either text file is updated. As soon as the time at which the file has last been changed updates said file is read by the corresponding python script and the task attached to that letter or number starts executing. Table 4 demonstrates what letters or numbers correspond to which files and what tasks are attached to these letters or numbers.

Robot writer file	**What is done by the camera code**	**What is done by the robot code**
"Start introduction"	The camera code is waiting for input to be sent to the camera writer file	The robot starts executing task 1 : "introSpeech" After this is finished it sends "Start analysing the 1st exercise" to the file Camera_writer.
"Start explaining the 2nd exercise"	The camera code sends "Start explaining the 2nd exercise" after the first exercise has been repeated four times successfully. When this is, is described in section 6.4.2.	The robot starts executing task 2 : "move1" After this is finished it sends "Start analysing the 2nd exercise" to the file Camera_writer.
"Start explaining the final exercise"	The camera code sends "Start explaining the final exercise" After the second exercise has been repeated four times successfully. When this is, is described in section 6.4.2.	The robot starts executing task 3 : "move2" After this is finished it sends "Start analysing the last exercise" to the file Camera_writer.
"Tell user stretch is good"	The camera code sends "Tell user stretch is good" once a person stretches their legs the correct way based on the posture analysis. When this is, is described in section 6.4.2.	The robot starts executing task 4 : "goodStretch" Afterwards it waits for new input.
"Tell the user to adjust their form"	The camera code sends "Tell the user to adjust their form" when the user starts to falter in a posture. When this is, is described in section 6.4.2.	The robot starts executing task 5 : "notGood" Afterwards it waits for new input.
"Tell the user they have finished a repetition"	The camera code sends "Tell the user they have finished a repetition" when the user has successfully finished one repetition of an exercise. When this is, is described in section 6.4.2.	The robot starts executing task 6 : "finishedRep" Afterwards it waits for new input.
"Tell the user adjust squat form"	The camera code sends "Tell the user adjust squat form" when the user has an incorrect squat posture. When this is, is described in section 6.4.2	The robot starts executing task 8 : "adjustSquat" Afterwards it waits for new input.
"Outro speech"	The camera code sends "Outro speech" once the last exercise (triggered by "Start analysing the last exercise" in Camera_writer) has been succesfully finished	The robot starts executing task 7 : "afronding" Afterwards the program is finished.

TABLE 3: *Table describing the robot writer file triggers and what consequently happens in the codes.*

Camera writer file	What is done by the camera code	What is done by the robot code
"Start analysing the 1st exercise"	The camera code starts task 1: "seat1calculator" based on how the user performs the robot sends "Start explaining the 2nd exercise" in case of successful completion, one of "Tell user stretch is good","Tell the user to adjust their form","Tell the user they have finished a repetition" to update the user on their performance.	The robot waits to receive one of these triggers :"Start explaining the 2nd exercise","Tell user stretch is good","Tell the user to adjust their form","Tell the user they have finished a repetition" .
"Start analysing the 2nd exercise"	The camera code starts task 2: "seat2calculator" based on how the user performs the robot sends a trigger: "Start explaining the final exercise" in case of successful completion, one of "Tell user stretch is good","Tell the user adjust squat form","Tell the user they have finished a repetition" to update the user on their performance.	The robot waits to receive one of the numbers :"Start explaining the final exercise","Tell user stretch is good","Tell the user adjust squat form","Tell the user they have finished a repetition" .
"Start analysing the last exercise"	The camera code starts task 1: "seat1calculator" based on how the user performs the robot sends a trigger:"Outro speech" in case of successful completion, one of "Tell user stretch is good","Tell the user to adjust their form","Tell the user they have finished a repetition" to update the user on their performance.	The robot waits to receive one of the numbers :"Outro speech","Tell user stretch is good","Tell the user to adjust their form","Tell the user they have finished a repetition" .

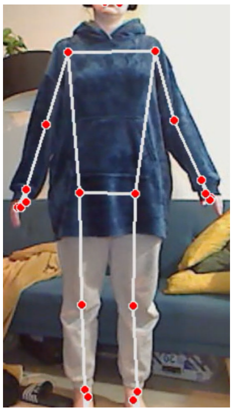
TABLE 4: *Table describing the camera writer file triggers and what consequently happens in the codes.*

6.4.2 Posture analysis

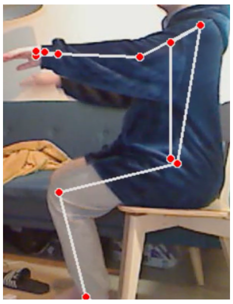
The posture analysis or rather exercise form analysis is done using cv2, mediapipe and math. These are frameworks/libraries which are easily accessible through python. First a function to calculate the angle between three points is made. This function can then be used in all three separate posture functions to calculate the angle of certain joints, such as the knee. For this the math library is used as this allows for the addition of certain calculations such as taking the root and calculating the cosine. These are needed to find the correct angle made in the joints of the user.

cv2 allows for the capture and analysis of video data. The video is captured through an external camera which can be positioned such that the users entire body is visible when performing exercises. The camera used is the logitech Quickcam pro 9000 (see figure 23) The capture of the video gives mediapipe something to analyse. Using mediapipe points are mapped to the users joints (see figure 24), these points are then put into the the angle calculator function to find the angle of a joint. For example for the knee joint the hip point, knee point and ankle point are put into the angle calculation function, this in turn will provide the angle of the knee joint. These angles can be used to calculate a users performance of the exercises. As long as they stay between certain ranges they are performing the exercise the right way.

FIGURE 23: *The logitech Quickcam pro 9000*



((A)) Standing posture



((B)) Sitting posture

FIGURE 24: *The points generated by mediapipe which are used to calculate posture through joint angles*

Once one of the letters: A,B, or C is read from the Camera_writer file the analysis of one of those postures starts. As described in table 4 once the code for posture recognition recognizes "A" it starts the seat1calculator function. This function corresponds to the first exercise described in section 5.3.1. It checks if the person has started the exercise and then starts checking their posture for said exercise. If they do well a repetition is added to their count which, when it reaches four, will end the exercise checking and trigger the next task in NAO.

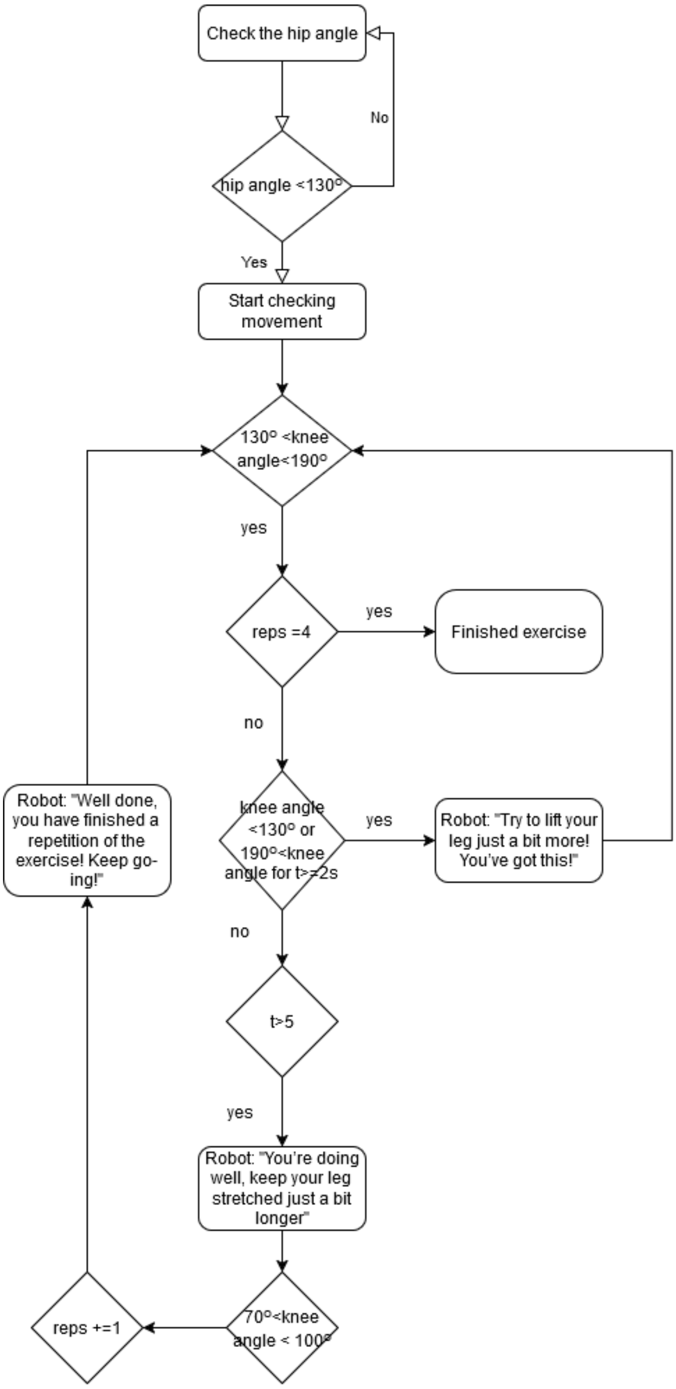


FIGURE 25: *A flow diagram depicting the calculations done to decide a users execution of movement 1*

A similar method was used for the second movement described in section 5.3.1. This calculation is performed by the function seat2calculator. It checks if the person is performing the squat and once it decides they are it checks their posture. If they are doing well the corresponding numbers are sent to the robot_writer file so NAO can instruct them.

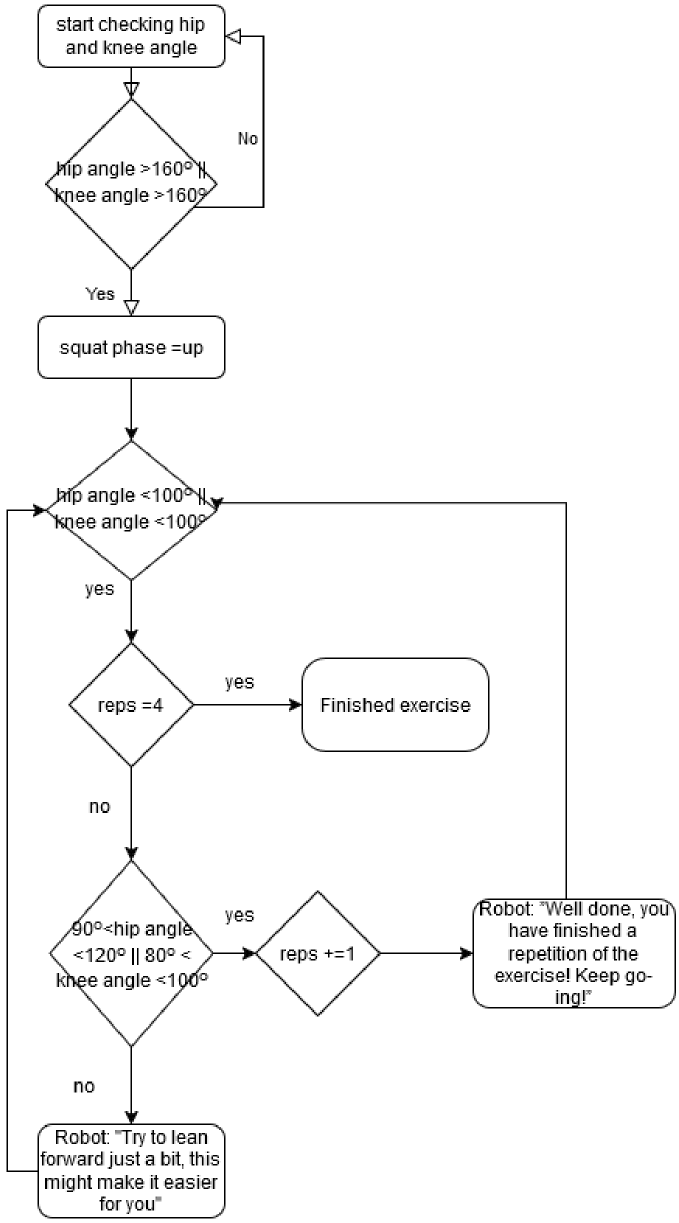


FIGURE 26: *A flow diagram depicting the calculations done to decide a users execution of movement 2*

The last exercise involves the user laying on the ground. The calculator checks if the person is performing the exercise correctly by slightly straightening out their leg if they do so the repetition count goes up.

6.4.3 NAO as a coach

NAO also makes use of python additions, it uses ALProxy from naoqi. Specifically it uses; ALTextToSPeech, ALTracker, ALMotion, ALRobotPosture,ALLeds, and ALAnimationPlayer. It uses these to track the user, this is done using ALTracker and ALMotion and indicated through the use of ALLeds, and to communicate with the user using ALTextToSpeech, AlRobotPosture, and AlAnimationPlayer.

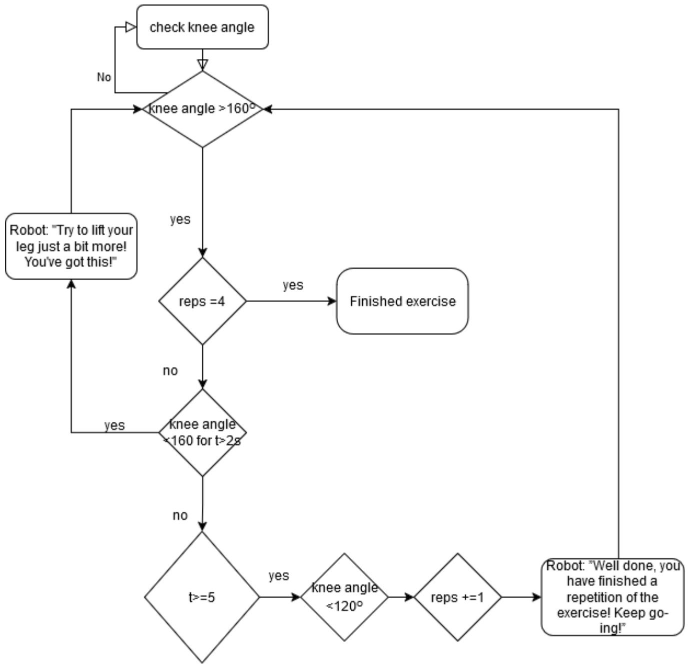


FIGURE 27: *A flow diagram depicting the calculations done to decide a users execution of movement 3*

When the robot turns on it starts tracking the user, making them aware that it knows they are there. Just as the posture analyser starts once it receives input from a text file so does NAO. As mentioned before in table 4 certain numbers trigger certain tasks. These tasks are voice lines the robot says. the tasks and corresponding voice lines are described in table 5. These voice lines are meant to encourage the user and clearly instruct them on the movement they are expected to perform. This integrates the BCT 4.1 and 8.1 into this part of NAOs assistance.

Task to perform	**Voice line corresponding to the task**	**English translation of the voice line**
introSpeech	”Hallo, mijn naam is NAO! Vandaag ga ik je begeleiden terwijl je bepaalde oefeningen uitvoert. Ik zal beginnen met het uitleggen van de eerste beweging. Pak alsjeblieft een stoel en ga hier op zitten zo dat ik uw zei profiel kan zien. Daarna begint u met uw linker been optillen tot het gestrekt voor u uitsteekt. Dit houdt u dan vast voor 10 seconden en dan laat u het been weer rustig zakken. Herhaal deze beweging daarna voor uw rechter been.”	”Hello, my name is NAO! Today, I will guide you while you perform certain exercises. I will start by explaining the first movement. Please take a chair and sit on it so that I can see your side profile. Then, begin by lifting your left leg until it is stretched out straight in front of you. Hold this position for 10 seconds and then gently lower your leg again. Repeat this movement afterward with your right leg.”
move1	”Oke, nu dat u succesvol de eerste beweging hebt uitgevoerd is het tijd voor de volgende beweging. Voor deze beweging heeft u ook een stoel nodig. De beweging lijkt op een squat, u strekt uw varmen voor u uit en staat dan langzaam op. Nogsteeds met de armen gestrekt gaat u weer zitten.”	”Okay, now that you have successfully completed the first movement, it is time for the next movement. For this exercise, you will also need a chair. The movement resembles a squat: stretch your arms out in front of you and then slowly stand up. With your arms still stretched out, slowly sit back down again.”
move2	”Nu is het tijd voor de laatste beweging, hiervoor moet u op de grond op uw rug gaan liggen. Suzanne zal u een opgerolde handdoek aangeven die u onder uw knieholtes moet leggen. Vanuit daar gaat u eerst uw linker onderbeen optillen tot dat uw been gestrekt is terwijl uw knieholte nog op de handdoek ligt”	”Now it is time for the final movement. For this, you need to lie on your back on the floor. Suzanne will hand you a rolled-up towel, which you should place under your knees. From there, start by lifting your left lower leg until it is straight, while keeping your knee resting on the towel.”
goodStretch	”U bent goed bezig houdt uw been nog even gestrekt”	”You’re doing well, keep your leg stretched just a bit longer”
notgood	”Probeer uw been wat meer op te tillen, nog even doorzetten! U kan dit!”	”Try to lift your leg just a bit more! You’ve got this!”
finishedRep	”Goed gedaan u heeft de oefening een keer herhaald! Houdt vol”	”Well done, you have finished a repetition of the exercise! Keep going!”
afronding	”Bedankt voor bewegen met mij, ik hoop dat u er van heeft kunnen genieten! Tot morgen”	”Thank you for exercising with me, i hope you enjoyed it! See you tomorrow!”

TABLE 5: *Table describing the sending and receiving of information through the two text files*

7 Evaluation

7.1 Study design and its aims

To evaluate the developed high-fi prototype a user evaluation was conducted. This user evaluation is based on the method described in section 3.4.4. The participants took part in a think aloud session, filled in the attrakdiff survey and were interviewed, the procedure further describing these methods is further elaborated upon in section 7.4. Through this user evaluation the fifth and final sub-research question is answered. This was done by assessing the user experience, is the robot intuitive, do they enjoy the robot, and the usability of the robot.

7.2 Participants

According to Nielsen and Landauer [84] with just 5 user test participants up to 80% percent of usability issues in a project can be detected. Hence, the aim was to achieve 5 participants over the age of 45 (with knee osteoarthritis) to test the high-fi prototype. Although to allow for thorough assessment of the usability and efficacy of the prototype testing with the target audience is required, this target audience was not obtained successfully.
To acquire participants fitting with the target group, first the artrosegezond group was contacted as they have a large group of people with OA willing to help in research projects. There was one response after months apologizing for their late response and expressing interest in helping, after which there was no more communication. Next 6 physical therapist groups were contacted, one responded saying they had no fitting group for these tests, the others did not respond. Later 5 community centres were contacted three responded, 2 expressed interest after which they changed their minds due to lack of space and facilities. The third one said they would be interested, then did not pick up contact again after stating they would invite the researcher to test for a yet unknown date. One of the two community centres whom expressed interest in testing did state the wording of the email and information letter was confusing. Lastly, posts were made in three OA, and other joint disease, Facebook groups.
Hence testing with proxy users was done. These proxy users are students at the university of Twente, they were recruited through convenience sampling. Eight participants were found for the user test. The tests were performed in a testing room on the university of twente campus (H106 in the citadel building).

7.3 Data collection

The test was conducted with proxy users, some discernable data was collected from these users and can be found in table 7 Focus was aimed at their response to the prototype and their interactions with it.
During the testing some evaluation methods were used to assess the usability and user experience of the prototype. These evaluation methods are described in table 6.

Aspect	Evaluation method
Usability	observations: How do the participants respond to the robot speaking to them? Are the participants able to finish all three tasks? Questions: How did you experience the robot? Do you understand why the robot advised you the way it did? What would you change about the robot? Where would you put the robot in your house?
User experience	Observations: What emotion is shown while using the robot? Questions: AttrakDiff questionnaire How did you feel while using the robot? What would you change about the robot? Would you use or recommend this robot? Do you feel the robot has an added benefit in regards to safe exercising and routine building thereof?

TABLE 6: *Table describing the evaluation methods used during the assessment of usability and user experience*

7.4 Procedure

The entire evaluation takes +/- 30 minutes and is conducted as follows:

1. The researcher introduces themselves and the project to the participant.
2. The researcher presents the participant with the information letter (appendix E) and consent form (appendix F), the participant reads both. The researcher presents the participant with an opportunity to ask questions, after which the participant signs the consent form.

3. The audio recording is started by the researcher.

4. The participant is informed the three tasks will be started and is asked to perform these tasks. They are then prompted to think aloud. The tasks are described below:

   - The participant starts a health dialogue with NAO. NAO explains that it will be asking a series of questions relating to the users physical health, activity level, pain in the joint, and inflammation, with which NAO asses what type of exercise is fit. The researcher tells the user in advance that clearly enunciating is important.
   - The researcher tells the participant they will be performing a type of exercise with NAO, and tells them to try to avoid asking the researcher questions during the routine. If the participant can not figure it out with NAO then they can ask the researcher. Then NAO explains that it and the user will be performing a yoga routine together and tells them to follow along as close as comfortable for them.
   - The researcher explains that the user will be performing three exercises, one of which on the ground (on a yoga mat) and if they wish to skip this exercise they should feel free to do so. Again the participant is reminded to try not to ask questions and figure it out with NAO first. They are also told they can start the exercises once NAO is finished explaining the exercise, and that NAO will indicate once they have finished a repetition of the exercise successfully. NAO then starts explaining the first exercise and providing feedback, which is then repeated for the second and third exercise.

5. The researcher takes notes (observations) of the participant their performance.

6. The participant is asked to fill in the attrakdiff questionnaire after finishing the tasks.

7. The semi structured interview is performed to obtain more insight into usability and user experience. In this interview questions relating to, usability, user experience, want to use, and points of improvement are posed. The exact questions asked can be found in appendix H.

8. The participant is thanked for their participation and a copy of the consent form/information letter is given to them.

7.5 Results

In this section the results found through eight user tests are discussed. These are divided into three categories, observations, questionnaires, and interviews. First, the overall perception of the robot is discussed, which includes the discussion of the attrakdiff questionnaire, then the observations and interviews are discussed per task. below in table 7 some participant characteristics per participant are shown.

Participant	Gender	Age Group	Knee Issues	Activity frequency
1	F	20-30	NO	Weekly
2	M	20-30	YES	weekly
3	F	20-30	NO	sedentary
4	M	20-30	YES	sedentary
5	M	20-30	NO	weekly
6	F	20-30	YES	weekly
7	F	20-30	YES	sedentary
8	F	20-30	NO	Daily

TABLE 7: *Data on Participants' Characteristics*

7.5.1 Robot overall

Aside from the tasks the robot was able to perform other points of attention included its appearance, the users desire to use it or even recommend it to others. These points are discussed here.
6/8 participants liked the robots appearance, they thought the robot was cute or cool in its appearance.

> *"[participant 6](translated) At first sight I think the robot is really cute, so I am intrigued to do something together[...] I am just curious what it is going to do "*

From the other two one did not like the robots appearance and the other was indifferent, they suggested the robot might be more appealing if it was more human like in its appearance, as the placement of the robots knees was confusing to them.

Another recurring point, mentioned by 4/8 participants, relating to the robots appearance, or rather its physical presence was that the robot being physically there might help in motivating the users. They mention that there are video guides that already exist which are often ignored. The robot also serves as a physical reminder that the user has to perform exercise.

> *"[participant 7](translated) Without the robot i really wouldn't be doing that!"*

The place where the robot would be placed in the users house was also a point of consistency. 4/7 participants, one did not answer the question as they would not use the robot themselves, would place the robot in their living room. They said that this was a place where they would have space in their house. 2/7 considered their bedroom as an option as this has more privacy. A suggestion made by one of the two who picked the bedroom also suggested that the robot could be placed in a public gym as a real personal trainer.

An additional point of discussion of the robot overall is its speech, here the tone,speed, and grammar are of importance. If the texts spoken were understood is discussed per task in sections 7.5.2, 7.5.3, and 7.5.4. The consensus, by those who discussed it (4/8 participants), was that the robot is polite but can speak rather quickly, in addition to its quick speech some words were pronounced in a confusing manner which threw users off. A suggestion made by 3/8 participants was to use more advanced AI such that the voice is more human-like, a similar suggestion made was to have a person record all the voice lines so that the robot sounds more like a person. This was suggested with the idea that the robot might then elicit more empathy from its users.

Finally, the users were asked if they would use the robot themselves and if they would recommend the robot to others. 6/8 of the participants would use the robot themselves, for some this came with a caveat. This caveat was, increased communication/feedback from the robot (mentioned by 2/6). the two participants who would not use the robot prefer exercising on their own and prefer not to use a guide tool as they already know how to do their exercises.
All participants (8/8) would recommend the robot but again with some caveats. These caveats include the one mentioned above of increased feedback(2/8), it does not cost too much money (1/8), and an increased understanding by the robot (1/8).

7.5.1.1 Attrakdiff Questionnaire

As stated in section 3.3, the attrakdiff questionnaire focusses on usability and user experience. These are divided into sub groups described by: **PQ**: which measures usability, efficiency, and effectiveness of the tested product. **HQ-I**: which measures emotional reaction and a persons perception of the products alignment with their identity. **HQ-S**: which measures emotional reaction and a persons perceived stimulation in the form of newness, creativity, excitement, and captivation of the product. **ATT**: describes the overall value of a product for the user.
These can all be rated on a scale form -3 to 3 where -3 is the entirely negative perception of the product, 0 is neutral and 3 is the entirely positive perception. This rating is based on the decisions made by participants on which antonyms fit closest with their experience with the product. They chose for 28 word pairs on a scale which word was most fitting to them. These antonyms can be seen in appendix G.

The results of the Attrakdiff questionnaire reflect those of the observations and interviews in that they lean towards a want for use indicated by the participants. The results of the questionnaire can be expressed in a multitude of ways. Two of which provide a picture of the interpretation of the product by the user.

The first one is called the portfolio of results and is depicted in figure 28. This graph essentially depicts the user's perception of the prototype based on its hedonic- and pragmatic quality. The two blue rectangles show the results found using the questionnaire. The darker one shows where the product placed on the plot and the lighter one depicts the confidence in the results. The smaller the confidence rectangle the less coincidental the results are. For this project the confidence for pragmatic quality is 0.47 and for the hedonic quality 0.31. This means that the results of the questionnaire did vary over these eight participants. However, these results can be put into a number score, for PQ this score is 0.88 and for HQ it is 0.92. These numbers imply that the robot was positively received, however there is varying interpretation of the users usability and the users experience with it. These varying opinions on the prototype are further discussed in sections 7.5.2,7.5.3,and 7.5.4.

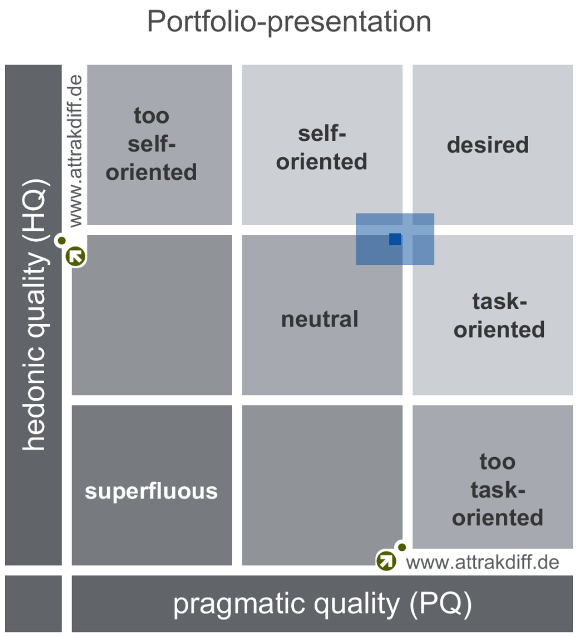


FIGURE 28: *Portfolio of results found with the Atrakkdiff questionnaire.*

Next the scoring per each of the four scales, as discussed in section 3.3, is determined the scoring of these four scales can range from -3 to 3. On this scale a negative score means a negative user experience, 0 means a neutral experience, and 3 means a positive experience. in table 8 the number scores acquired for this prototype are shown. Overall

Scale	Score
Pragmatic quality - PQ	0.88
Hedonic quality identity - HQ-I	0.91
Hedonic quality stimulation - HQ-S	0.93
Attractiveness - ATT	1.45

TABLE 8: *The number scores achieved in the attrakdiff questionnaire per scale, which are based on the word pair scores depicted in appendix J*

the robot scores similarly for the first three scales deciding the users general desire for the product in terms of user experience. While on attractiveness (ATT) the robot scores a bit better. As discussed before in section 3.3, The overall desire of the product is based on the combination of pragmatic quality and hedonic quality. This means that the usability and effectiveness (PQ),the emotional reaction and alignment with identity (HQ-I), and the captivation and excitement (HQ-S), of the robot were all rated to be mostly positive. Lastly, the overall value of the robot, which is described by ATT, scored slightly better.

7.5.2 Health dialogue

The first task for the evaluation was the health dialogue. As mentioned in 7.4, the task entails the user speaking with the robot to discuss their physical well-being. A few observations and interview results are of relevance here, these are described below.
Two important observations were made during the think-aloud sessions. The first being that 5/8 participants were confused on when to speak to the robot. They either, waited a

very long time for the robot to indicate when they could speak, or accidentally interrupted the robot while it was speaking. This is also reflected during the interviews.
Another observation, made with 3/8 participants, was that when the robot told them to speak in a loud tone, they interpreted this as screaming at the robot.

All participants were able to finish the health dialogue part of the test. During the interviews, they were asked if they understood the advice they got and why they got this advice. 6/8 participants thought they understood their advice and could explain it back. 1 participant forgot their advice and hence did not dare to say if they understood and another could not be sure if they understood.
The robot having different responses to the answers the users provide, made some of the users(3/8) feel understood/supported. One even said they felt emotionally supported by the robot.

> *"[Participant 8](translated) Then I did feel emotionally supported!"*

> *"[Participant 7](translated) So also that he kind off moves like a human being and that he really talks to you, that does feel nice."*

An addition or change to be made to this interaction with the robot, which was mentioned by 6/8 participants, is to ensure a broader understanding of dialogue by the robot. They would want access to more interactions with the robot, so that it feels more like an actual conversation instead of a limited interview. They (3/6) would want the robot to have an option for a repeat command so that they could indicate that the robot should repeat an explanation or question for them.

7.5.3 Yoga routine

The second task during testing was performing the yoga routine. As mentioned in 7.4, some important observations were made in addition to some relevant points discussed during the interview, these are discussed below.

Prior to the start of the yoga routine NAO explained to the user to try to follow along as close as the user was capable of. Then it tells them not to overexert themselves, by telling them not to do anything that makes them uncomfortable. Despite this advice 4/8 participants complained of the exercises being difficult to hold during the think-aloud session.
Another point of attention was the lunge move, prior to starting the move NAO tells the user which leg has to go in front of them (the user) 5/8 participants put a different leg than expected of them in front of them.
Despite some struggle by participants all of them (8/8) were able to finish the yoga routine.

Something that was enjoyed by 5/8 participants was the combination of both demonstration, explanation, and motivation provided during the yoga routine. A participant who does their own stretch routine even said:

> *"[Participant 3](translated) Yes I think it is pretty fun, I would use him tomorrow for my stretching routine."*

Some points of improvement/addition mentioned by the participants were, explain the movement prior to demonstration of said movement(1/8), decreased speed of the yoga routine (1/8), it perceives the user during yoga and gives feedback on their form (1/8).

3/8 participants preferred the yoga routine, while 2/8 preferred the guided exercise, 2 had no preference and a last one would prefer a mix of both the yoga routine and the guided exercise routine.

7.5.4 Guided exercise routine

For the third and final task, the guided exercise routine, as mentioned in 7.4, the robot explains certain exercises to the user, monitors their performance, and provides feedback thereon. An observation and interview results are of relevance here, these are described below. Due to a technical issue during one of the tests, one participant was unable to perform this task, hence the total of participants here is 7 instead of 8.

Despite the explanation of when to start provided by the researcher, multiple participants were confused on when to start the exercises. 3/7 participants looked towards the researcher for indication of when to start.

During the interview more points came to light. All participants enjoyed the robot explaining the exercises and checking their form. Not all for the same reason, the three recurring reasons are quoted below.

> *"[Participant 5](translated) [...] more useful, because then you have a sort of personal-trainer."*

This can take away the anxiety of doing an exercise wrong, similar points were mentioned by 3/7 participants.

> *"[Participant 7](translated) He is really focused on motivation, that you are really doing something."*

Some might struggle in motivating themselves, which was mentioned by 3/7 participants, the robots motivation can be of help, this was mentioned by 4/7 participants.

> *"[Participant 8](translated) Well, [...], I think it is a cool idea, that it can see what the user is doing and then gives feedback on that!"*

This was mentioned by 2/7 participants.

An important point of improvement is the rate of feedback provided by the robot. This was mentioned by 6/7 participants. They would like to know when the robot sees them, an indication of when they should start said out loud, and more indication of where they are in an exercise. A recurring point was how long they should hold an exercise:

> *"[Participant 4](translated) [...] indicate when it is, and especially the ten seconds with your leg raised, that it tells you okay you have ten seconds, switch leg."*

One participant saw no issue with the robots feedback and indicated they would not change the feedback.

> *"[Participant 2](translated) With regards to functionality, that is good!"*

Lastly one participant mentioned adding LEDs in the crux of the robots joints as to indicate which joints should be moved. This would have provided them with further clarity.

7.6 Evaluation of realisation

During the specification phase final requirements were set. To evaluate the final realisation of the concept these requirements are considered here. If these requirements were met can be seen in table 9. In said table it can be seen that requirement 2,5,and 12 have been partially met. This means that although in some capacity it could be said the robot met this requirement there is some further explanation needed as to the capacity in which the requirement was met.

For requirement 2 during the user evaluation it was found that some parts of the robot, such as when to start talking to it, or when to switch legs during exercise, were not intuitive to the users. While others parts such as following the robots movement, and why the users got the advice was intuitive to the users. Hence the robot should be considered as partially intuitive.

For requirement 5 during the user evaluation two participants expressed worry of over exerting themselves trough performing these exercises. However, both added that it could be attributed to their own interpretation of the robots wording. Despite these additions it should not be said with complete certainty that the robot never makes the user over exert themselves.

The last requirement partially met was requirement 12. The robot NAO 6 is capable of speaking many languages, which can be easily implemented. However, the prototype was developed with only Dutch dialogue after the prototyping phase.

Requirement number	Requirement	Priority	Requirement Met?
1	The robot must implement BCTs [74]	must	YES
2	The robot must be intuitive in its use.	must	PARTIALLY
3	The robot must have use sessions of 20 minutes or less.	must	YES
4	The robot must encourage daily exercise	must	YES
5	The robot must be safe to use, the user should never over exert themselves while using the robot.	must	PARTIALLY
6	The robot should be enjoyable in its use.	should	YES
7	The robot should provide varied exercise options	should	YES
8	The robot should implement some for activity data gathering	should	YES
9	The robot should implement mobility training (yoga)	should	YES
10	The robot should respect the users privacy	should	YES
11	The robot could function independently from other devices.	could	NO
12	The robot could speak multiple languages.	could	PARTIALLY
13	The robot will not deal with mental well-being.	won't	YES
14	The robot will not join the user on walks or exercises outside of the set body weight and yoga exercises.	won't	YES
15	The robot will not and should not act as a health-care provider.	won't	YES
16	The robot will not save user data.	won't	YES

Table 9: Requirement evaluation for the high fidelity prototype

7.7 Summary of results

Overall, the robot was positively received as a motivational and effective exercise assistant, with participants appreciating its physical presence, guidance, and motivational features. However, improvements in intuitiveness, communication, and task-specific feedback are necessary to enhance its usability and user experience. While the prototype demonstrated promising potential, addressing these areas will be critical to ensuring the robot meets all design requirements and achieves greater user satisfaction.
This is reflected in the Attrakdiff results with a score of 0.88 for pragmatic quality and a score of 0.92 for the hedonic quality. Which means the robot scores okay on both usability and user experience.

8 Discussion and future work

The developed prototype appears to be a promising solution, for which both strengths and improvement points have been identified. The subsequent chapter delves into the principal findings, evaluates the strengths and limitations of this thesis, and provides recommendations for future research and development.

8.1 Principal findings

The aim of this thesis was to design a social robot which can help guide KOA patients to and through exercises for disease self management. In this thesis 6 BCTs were found and implemented in a social robot through an iterative process to develop a personal exercise guide. This robot was then evaluated based on user evaluation and requirement reflection.

Based on user evaluation the prototype seems to be received well based on its usability and the user experience of the participants. However, due to the use of proxy users no clear conclusion can be drawn for the robots application with the target group of KOA patients. Fitting with the effective BCTs found by Gilchrist et al. [76] The robot was mostly successful in guiding the users to exercise as most participants fully understood why and what advice they got for the exercise they should do. Additionally, the robot was partly successful in guiding the users through the exercise as all participants, who performed the exercises, were able to finish both the yoga routine and guided exercise routine. These findings are a result of the successful implementation of the found BCTs: "action planning", " instructions on how to perform a behaviour", "graded tasks", "demonstration of behaviour", and "behavioural practice/rehearsal".

Most participants could see themselves be motivated by the robot and learning these exercises so they could perform them on their own. This implies that the BCTs were successfully implemented within the robot. However, if the participants knew and recognised these BCTs was not explicitly asked it can not be said with certainty that these would be successful in their application. Additionally, to test for their success a longitudinal study would have to be performed as BCTs only take effect after time.

Although most users were open to using the robot themselves, and all of them would recommend the robot to others multiple points of improvement were discussed by most of them.
The rate of feedback provided by the robot should be increased, this was a recurring suggestion throughout user testing. Specifically during the health dialogue users would like the addition of an indication when the robot is ready to listen to them. The same goes for the guided exercise routine, most users would want more input from the robot, if it sees them, how long they have been holding an exercise, and when they should repeat or switch. This is important to consider as this implies that the users felt under-supported during the exercises. The desire for continuous and instantaneous feedback fits with the results found by Toyama et al. and Avioz-Sarig et al. [67],[4].
Another suggestion made was to increase the robot's dialogue, to change its voice to sound more human like, as this would elicit more of an emotional reaction and form an empathic bond between user and robot. However, the ethical implications of this suggestion should be considered. From the literature it was found this should be avoided as it is inherently deceitful. This suggestion could indicate the users do not mind this and adds this addition of emotion as a consideration for future work. Which goes against the suggestion made

by Prescott and Robillard [69] that robots are inherently deceitful which should make the user want to use the robot less. Moreover, Fong et al. [20] state that coded dialogue perceived by the robot could add a bias in the robot, making it less acceptable to their human counterparts.
Lastly the requirements were evaluated based on them being met. All but one requirement was met or partially met. The partially met requirements could be considered met. However, as there is still uncertainty there; if the robot is intuitive, and there is no chance for over exertion, hence these are considered to be partially met. Lastly, due to difficulty with the outdated software of the robot it was not possible to make the robot work separately from other devices. Hence this requirement was not met.

8.2 Strengths and limitations

Throughout the project multiple strengths and limitations were determined. These are divided into two subgroups which were the main parts during the designing of the social robot NAO. Product development includes all parts from the literature review to the final realisation, the product evaluation includes the evaluation of said product.

8.2.1 Product development

For this thesis, extensive and strong background research was performed. It spans the disease and its symptoms, possible management options for the disease, and current solutions which findings were used as a basis for the brainstorming session for a possible solution.

Another identified strength is the broad brainstorming done before a final decision was made on which solution could fit best. Additionally, the final three solutions were discussed with experts which gave a stronger basis for the final solution. They provided further insights into the idea which then led to additions which made it more well-rounded.

Another strength is the several parts of prototyping done for the development of the robot. Each task developed for the robot had prototyping further honing in on the best fitting solution through adjustment of the prototype. This led to a more understandable and concise interaction.

A last strength was the addition of BCTs to the robot. Due to the preferred short time frame of use by the users found in the literature review, a solution which was temporary had to be thought of. To ensure the solution could be temporary the exercises should be learned and become a standard behaviour for the solutions user. Through the addition of BCTs to the project this is something which could be realised, which fits with the findings of successful BCT implementation by both Gilchrist et al. [76] and Arnautovska et al. [77]. To make sure this is successful more in depth testing is needed.

A first limitation of this thesis is the lack of definitive proof found for which type of exercise is best for the management of KOA pain symptoms. During the literature review, research into exercise as a form of disease self management was explored. However, no clear amount or type of loading is known as to be safe or not safe for KOA patients. This was later discussed with experts of the LOAD project, they suggested making certain assumptions for the product development as they agreed there is no known amount of loading to be safe. These assumptions were then used as a basis for the decisions made in the health dialogue. This could have effected the application and advice provided by the robot.

Another limitation was the available visual coding program choregraph. This program seemed easy in use initially but was extremely limited in its options. This led to both the health dialogue and yoga routine coming out different form intended. A solution would have been implementing this code in another coding program such as python, as was done for the posture recognition.

Lastly due to the robots outdated software it was not possible to use newer libraries, APIs, and frameworks for the robot. Python and the corresponding software have progressed further away from NAOs version limitations, which means that new advancements in AI could not be implemented with the robot. There are frameworks out there which allow for the integration of different versions of python, but the implementation of these frameworks fell outside of the scope of this project hence the solution with text writing was used. This allowed for communication between the versions of python. Applying these frameworks could have made the final prototype more well rounded and more intuitive in its use.

8.2.2 Product evaluation

A strength found for the evaluation of the project was the full adjustment of the test to the target group. The explanation of the project in the letter and by the researcher were adjusted to be respectful of the target audience and understandable for them.

A first limitation of the evaluation was the use of proxy users for evaluation instead of the target audience. The acquisition of testers from the target audience was unsuccessful despite multiple attempts to find participants. First the artrosegezond group was contacted as they have a large group of people of OA willing to help in research projects. There was one response after months apologizing for their late response and expressing interest in helping, after which there was no more communication. Next 6 physical therapist groups were contacted, one responded saying they had no fitting group for these tests, the others did not respond. Later 5 community centres were contacted three responded, 2 expressed interest after which they changed their minds due to lack of space and facilities. The third one said they would be interested, then did not pick up contact again after stating they would invite the researcher to test for a yet unknown date. One of the two community centres whom expressed interest in testing did state the wording of the email and information letter was confusing. Lastly, posts were made in three OA, and other joint disease, Facebook groups. These posts were liked but no response was received expressing interest in testing. Based on the one response expressing confusion from one of the community centres the wording of the emails and posts might have confused potential test participants leading to the lack of response.

Due to the aim of testing with the target group, and this falling through, proxy users were contacted belatedly. This belated acquisition led to a smaller test group than wanted for testing with proxy users. This means that the found results are based on a small user group and can not be taken as conclusive. Although the use of proxy users already limits the validity of the found results.

Another limitation of this research is the single use test, the robot is developed to help users in the self management of their disease. The aim for the robot is to be used for six months after which the user should be able to make their own informed decisions on when, what, and how they should be exercising. To test if the robot is capable of doing so a longitudinal test should be performed. However, due to the lack of time within this project this was not possible.

A last limitation was the setting in which the robot was tested. The robot is meant to be used within a home setting. Now the test was performed in a testing room (H106 of citadel) which did not look similar to a living space. Ideally, the robot would have been tested in the home of the participants as this would be most representative of this setting. However, on the campus of university of Twente there is a testing facility called eHOUSE, this might have helped in making the setting closer to a home environment. Adjusting the testing space might have provided more accurate results from the evaluation.

8.3 Future work

Some recommendations for the further development of this robot and testing there of are described below.
A first and fore most recommendation would be to add a more advance AI for text to speech and speech to text. That way the robot is capable of saying and understanding more. As stated by most participants this would increase their want to use the robot of their own. Additionally, this could improve the robot such that the target group is capable of easily using the robot independently.

A second recommendation would be to integrate movement, explanation and feedback on the movement. This way the users would be capable of having visual and auditory input on their movement, and their performance there of. By increasing the feedback the robot provides its instructions can also become clearer. This would lead to a more complete and clear in use robot.

Now the activity data received by the robot is self reported activity by the user. Integrating an activity tracking device into the robots application might make the decision making on what type of exercise the user should be doing more consistent. This could also allow the robot to make more accurate recommendations.
Once valid claims are published as to what type and amount of loading of the knee joint are published, these should be integrated into the robots advice and instructions for exercise. This will ensure the robot is as safe and comprehensive as possible.

Lastly, testing the robot in a longitudinal study with the target group, with a participant pool of 30-50, in their homes would allow for clear and accurate results of the effectiveness of the robot in its application.

9 Conclusion

The research question aimed to be answered by this thesis is:

How might a social robot be designed to aid in the self-management of knee osteoarthritis pain symptoms in patients through socially assisted exercise?

First a literature review investigating the disease and ways to combat it was performed. Additionally, the application of social robots came out as a potential solution, in addition to behaviour change techniques to have the users learn the behaviour of safe exercise leading to disease self management. Then based on the literature review, design tools, the creative technology design process, and expert opinions a robot was developed. This robot was then evaluated based on its meeting of set requirements and user testing. The user response was positive overall although suggestions were made for improvement of the robot. However, these users were proxy users and not part of the target group of KOA patients.

So to answer the research question; The social robot should implement BCTs within its guiding of exercises such that the decision on what, when and how exercise should be performed becomes a learned behaviour by its users. Additionally, prototyping should be performed and tested, throughout the research, with potential users to validate the adherence of the project to the users needs. Experts need to be brought in to develop the product for KOA patients. To conclude, further research into the product is needed to investigate its validity and the further opportunities it might offer. The product has great potential in the medical field by helping KOA patients self-manage their disease. The most appropriate next step is to test with the target group of KOA patients on a long term basis.

10 AI statement

During the preparation of this work the author used Grammarly in order to check the spelling and grammar of the thesis document. Additionally, ChatGPT was used to help solve problems relating to coding in the form of bug fixing. After using these tools/services, the author reviewed and edited the content as needed and take full responsibility for the content of the work.

References

[1] F. P. Luyten, P. Tylzanowski, and R. J. Lories, "Wnt signaling and osteoarthritis," *Bone*, vol. 44, no. 4, pp. 522–527, 2009.

[2] R. Khosla, M.-T. Chu, R. Kachouie, K. Yamada, F. Yoshihiro, and T. Yamaguchi, "Interactive multimodal social robot for improving quality of care of elderly in australian nursing homes," in *Proceedings of the 20th ACM international conference on Multimedia*, pp. 1173–1176, 2012.

[3] D. C. Tozadore, T. Lewko, and C. Wang, "Productive breaks in mentally challenging tasks: Comparing free-time pauses to stretching sessions guided by a social robot," in *Proceedings of the 11th International Conference on Human-Agent Interaction*, pp. 191–199, 2023.

[4] O. Avioz-Sarig, S. Olatunji, V. Sarne-Fleischmann, and Y. Edan, "Robotic system for physical training of older adults," *International Journal of Social Robotics*, vol. 13, no. 5, pp. 1109–1124, 2021.

[5] A. H. Mader and W. Eggink, "A design process for creative technology," in *16th International Conference on Engineering and Product Design, E&PDE 2014*, pp. 568–573, The Design Society, 2014.

[6] A. Gezond, 2023. artrosegezond website: https://artrosegezond.nl/wat-kunt-u-zelf-doen/gezond-bewegen-met-artrose.

[7] J. Crandel, 2023. Jason Crandel Yoga method : https://jasonyoga.com/2015/04/01/surya-namaskar-b/.

[8] S. Glyn-Jones, A. J. R. Palmer, R. Agricola, A. J. Price, T. L. Vincent, H. Weinans, and A. J. Carr, "Osteoarthritis," *The Lancet*, vol. 386, no. 9991, pp. 376–387, 2015.

[9] K. Sinusas, "Osteoarthritis: diagnosis and treatment," *American family physician*, vol. 85, no. 1, pp. 49–56, 2012.

[10] N. Vereinte, "Leaving no one behind in an ageing world," *World social report United Nations: New York, NY, USA*, 2023.

[11] C. Koliaki, M. Dalamaga, and S. Liatis, "Update on the obesity epidemic: after the sudden rise, is the upward trajectory beginning to flatten?," *Current Obesity Reports*, vol. 12, no. 4, pp. 514–527, 2023.

[12] N. C. G. C. UK, "Osteoarthritis: care and management in adults," 2014.

[13] N. J. Manek and N. E. Lane, "Osteoarthritis: current concepts in diagnosis and management," *American family physician*, vol. 61, no. 6, pp. 1795–1804, 2000.

[14] M. Maqbool, G. Fekadu, X. Jiang, F. Bekele, T. Tolossa, E. Turi, G. Fetensa, and K. Fanta, "An up to date on clinical prospects and management of osteoarthritis," *Annals of Medicine and Surgery*, vol. 72, p. 103077, 2021.

[15] N. J. Bosomworth, "Exercise and knee osteoarthritis: benefit or hazard?," *Canadian Family Physician*, vol. 55, no. 9, pp. 871–878, 2009.

[16] D. J. Hunter and F. Eckstein, "Exercise and osteoarthritis," *Journal of anatomy*, vol. 214, no. 2, pp. 197–207, 2009.

[17] T. McAlindon, R. Bannuru, M. Sullivan, N. Arden, F. Berenbaum, S. Bierma-Zeinstra, G. Hawker, Y. Henrotin, D. Hunter, H. Kawaguchi, K. Kwoh, S. Lohmander, F. Rannou, E. Roos, and M. Underwood, "Oarsi guidelines for the non-surgical management of knee osteoarthritis," *Osteoarthritis and Cartilage*, vol. 22, no. 3, pp. 363–388, 2014.

[18] D. F. Hamilton, S. Akhtar, B. Griffiths, Y. Prior, and R. K. Jones, "The use of technology to support lifestyle interventions in knee osteoarthritis: A scoping review," *Osteoarthritis and Cartilage Open*, vol. 5, no. 2, p. 100344, 2023.

[19] A. J. Johnson, S. Palit, E. L. Terry, O. J. Thompson, K. Powell-Roach, B. W. Dyal, M. Ansell, and S. Q. Booker, "Managing osteoarthritis pain with smart technology: a narrative review," *Rheumatology Advances in Practice*, vol. 5, no. 1, p. rkab021, 2021.

[20] T. Fong, I. Nourbakhsh, and K. Dautenhahn, "A survey of socially interactive robots," *Robotics and Autonomous Systems*, vol. 42, no. 3, pp. 143–166, 2003. Socially Interactive Robots.

[21] D. Feil-Seifer and M. J. Mataric, "Defining socially assistive robotics," in *9th International Conference on Rehabilitation Robotics, 2005. ICORR 2005.*, pp. 465–468, IEEE, 2005.

[22] J. Fasola and M. J. Matarić, "A socially assistive robot exercise coach for the elderly," *Journal of Human-Robot Interaction*, vol. 2, no. 2, pp. 3–32, 2013.

[23] L. Bishop, A. van Maris, S. Dogramadzi, and N. Zook, "Social robots: The influence of human and robot characteristics on acceptance," *Paladyn, Journal of Behavioral Robotics*, vol. 10, no. 1, pp. 346–358, 2019.

[24] X. Wang, D. Hunter, J. Xu, and C. Ding, "Metabolic triggered inflammation in osteoarthritis," *Osteoarthritis and cartilage*, vol. 23, no. 1, pp. 22–30, 2015.

[25] I. G. Arslan, J. Damen, M. de Wilde, J. J. van den Driest, P. J. E. Bindels, J. van der Lei, D. Schiphof, and S. M. A. Bierma-Zeinstra, "Incidence and prevalence of knee osteoarthritis using codified and narrative data from electronic health records: A population-based study," *Arthritis Care & Research*, vol. 74, no. 6, pp. 937–944, 2022.

[26] A. Mobasheri and M. Batt, "An update on the pathophysiology of osteoarthritis," *Annals of Physical and Rehabilitation Medicine*, vol. 59, no. 5, pp. 333–339, 2016.

[27] B. Abramoff and F. E. Caldera, "Osteoarthritis: Pathology, diagnosis, and treatment options," *Medical Clinics of North America*, vol. 104, no. 2, pp. 293–311, 2020. Physical Medicine and Rehabilitation: An Update for Internists.

[28] D. J. Hunter, J. J. McDougall, and F. J. Keefe, "The symptoms of osteoarthritis and the genesis of pain," *Rheumatic Disease Clinics of North America*, vol. 34, no. 3, pp. 623–643, 2008.

[29] B. Wise, J. Niu, Y. Zhang, N. Wang, J. Jordan, E. Choy, and D. Hunter, "Psychological factors and their relation to osteoarthritis pain," *Osteoarthritis and Cartilage*, vol. 18, no. 7, pp. 883–887, 2010.

[30] S. Lautenbacher, B. Kundermann, and J.-C. Krieg, "Sleep deprivation and pain perception," *Sleep medicine reviews*, vol. 10, no. 5, pp. 357–369, 2006.

[31] Elma, K. Brain, and H.-J. Dong, "The importance of nutrition as a lifestyle factor in chronic pain management: A narrative review," *Journal of Clinical Medicine*, vol. 11, no. 19, 2022.

[32] G. Musumeci, F. C. Aiello, M. A. Szychlinska, M. Di Rosa, P. Castrogiovanni, and A. Mobasheri, "Osteoarthritis in the xxist century: risk factors and behaviours that influence disease onset and progression," *International journal of molecular sciences*, vol. 16, no. 3, pp. 6093–6112, 2015.

[33] M. Szychlinska, R. Leonardi, M. Al-Qahtani, A. Mobasheri, and G. Musumeci, "Altered joint tribology in osteoarthritis: reduced lubricin synthesis due to the inflammatory process. new horizons for therapeutic approaches," *Annals of Physical and Rehabilitation Medicine*, vol. 59, no. 3, pp. 149–156, 2016.

[34] L. Dudaric, I. Dumic-Cule, E. Divjak, T. Cengic, B. Brkljacic, and G. Ivanac, "Bone remodeling in osteoarthritis—biological and radiological aspects," *Medicina*, vol. 59, no. 9, p. 1613, 2023.

[35] D. R. Lichtenstein, S. Syngal, and M. M. Wolfe, "Nonsteroidal antiinflammatory drugs and the gastrointestinal tract the double-edged sword," *Arthritis & Rheumatism: Official Journal of the American College of Rheumatology*, vol. 38, no. 1, pp. 5–18, 1995.

[36] D. J. Hunter and G. H. Lo, "The management of osteoarthritis: an overview and call to appropriate conservative treatment," *Rheumatic Disease Clinics of North America*, vol. 34, no. 3, pp. 689–712, 2008.

[37] B. Arroll and F. Goodyear-Smith, "Corticosteroid injections for osteoarthritis of the knee: meta-analysis," *Bmj*, vol. 328, no. 7444, p. 869, 2004.

[38] Z. Wu, X. Ding, G. Lei, C. Zeng, J. Wei, J. Li, H. Li, T. Yang, Y. Cui, Y. Xiong, *et al.*, "Efficacy and safety of the pulsed electromagnetic field in osteoarthritis: a meta-analysis," *BMJ open*, vol. 8, no. 12, p. e022879, 2018.

[39] C. D. Kurniawan, "The principle of non-pharmacologic management of osteoarthritis," *Indonesia Journal of Biomedical Science*, vol. 12, no. 1, 2018.

[40] P. P. Alfredo, J. M. Bjordal, S. H. Dreyer, S. R. F. Meneses, G. Zaguetti, V. Ovanessian, T. Y. Fukuda, W. S. Junior, R. Á. B. L. Martins, R. A. Casarotto, *et al.*, "Efficacy of low level laser therapy associated with exercises in knee osteoarthritis: a randomized double-blind study," *Clinical rehabilitation*, vol. 26, no. 6, pp. 523–533, 2012.

[41] "Osteoarthritis: New insights. part 1: The disease and its risk factors," *Annals of Internal Medicine*, vol. 133, no. 8, pp. 635–646, 2000. PMID: 11033593.

[42] D. Coggon, I. Reading, P. Croft, M. McLaren, D. Barrett, and C. Cooper, "Knee osteoarthritis and obesity," *International journal of obesity*, vol. 25, no. 5, pp. 622–627, 2001.

[43] C. Farrell, A. G. Shamrock, A. C. Black, and J. Kiel, "Anatomy, bony pelvis and lower limb: Medial meniscus," in *StatPearls [Internet]*, StatPearls Publishing, 2023.

[44] M. Englund, F. W. Roemer, D. Hayashi, M. D. Crema, and A. Guermazi, "Meniscus pathology, osteoarthritis and the treatment controversy," *Nature Reviews Rheumatology*, vol. 8, no. 7, pp. 412–419, 2012.

[45] A. N. Wilkins and E. M. Phillips, "Chapter 61 - knee osteoarthritis," in *Essentials of Physical Medicine and Rehabilitation (Second Edition)* (W. R. Frontera, J. K. Silver, and T. D. Rizzo, eds.), pp. 345–353, Philadelphia: W.B. Saunders, second edition ed., 2008.

[46] S. E. Willick and P. A. Hansen, "Running and osteoarthritis," *Clinics in Sports Medicine*, vol. 29, no. 3, pp. 417–428, 2010. The Runner.

[47] E. M. Bartels, C. B. Juhl, R. Christensen, K. B. Hagen, B. Danneskiold-Samsøe, H. Dagfinrud, and H. Lund, "Aquatic exercise for the treatment of knee and hip osteoarthritis," *Cochrane Database of Systematic Reviews*, no. 3, 2016.

[48] D. Duong and L. Vogel, "Overworked health workers are "past the point of exhaustion"," 2023.

[49] W. Choi, H. Zheng, P. Franklin, and B. Tulu, "mhealth technologies for osteoarthritis self-management and treatment: A systematic review," *Health Informatics Journal*, vol. 25, no. 3, pp. 984–1003, 2019. PMID: 29090628.

[50] T. Chen, C. K. Or, and J. Chen, "Effects of technology-supported exercise programs on the knee pain, physical function, and quality of life of individuals with knee osteoarthritis and/or chronic knee pain: a systematic review and meta-analysis of randomized controlled trials," *Journal of the American Medical Informatics Association*, vol. 28, no. 2, pp. 414–423, 2021.

[51] P. B. Shull, K. L. Lurie, M. R. Cutkosky, and T. F. Besier, "Training multi-parameter gaits to reduce the knee adduction moment with data-driven models and haptic feedback," *Journal of Biomechanics*, vol. 44, no. 8, pp. 1605–1609, 2011.

[52] P. Shull, K. Lurie, M. Shin, T. Besier, and M. Cutkosky, "Haptic gait retraining for knee osteoarthritis treatment," in *2010 IEEE haptics symposium*, pp. 409–416, IEEE, 2010.

[53] R. Argent, P. Slevin, A. Bevilacqua, M. Neligan, A. Daly, and B. Caulfield, "Clinician perceptions of a prototype wearable exercise biofeedback system for orthopaedic rehabilitation: a qualitative exploration," *BMJ open*, vol. 8, no. 10, p. e026326, 2018.

[54] R. Marks, "Robotics as a form of non surgical complementary osteoarthritis treatment," *International journal of Complementary and Internal Medicine*, vol. 5, no. 1, pp. 189–198, 2023.

[55] E. Papi, G. M. Murtagh, and A. H. McGregor, "Wearable technologies in osteoarthritis: a qualitative study of clinicians' preferences," *BMJ open*, vol. 6, no. 1, p. e009544, 2016.

[56] N. Shah, K. Costello, A. Mehta, D. Kumar, *et al.*, "Applications of digital health technologies in knee osteoarthritis: narrative review," *JMIR Rehabilitation and Assistive Technologies*, vol. 9, no. 2, p. e33489, 2022.

[57] T. Cudejko, K. Button, J. Willott, and M. Al-Amri, "Applications of wearable technology in a real-life setting in people with knee osteoarthritis: A systematic scoping review," *Journal of Clinical Medicine*, vol. 10, no. 23, p. 5645, 2021.

[58] R. Campa, "The rise of social robots: a review of the recent literature," 2016.

[59] B. Reeves and C. Nass, "The media equation: How people treat computers, television, and new media like real people," *Cambridge, UK*, vol. 10, no. 10, pp. 19–36, 1996.

[60] C. Breazeal, "Emotion and sociable humanoid robots," *International Journal of Human-Computer Studies*, vol. 59, no. 1, pp. 119–155, 2003. Applications of Affective Computing in Human-Computer Interaction.

[61] C. Breazeal, "Emotion and sociable humanoid robots," *International journal of human-computer studies*, vol. 59, no. 1-2, pp. 119–155, 2003.

[62] I. Leite, C. Martinho, and A. Paiva, "Social robots for long-term interaction: a survey," *International Journal of Social Robotics*, vol. 5, pp. 291–308, 2013.

[63] G. Laban, A. Kappas, V. Morrison, and E. S. Cross, "Building long-term human–robot relationships: Examining disclosure, perception and well-being across time," *International Journal of Social Robotics*, vol. 16, no. 5, pp. 1–27, 2024.

[64] R. Simmons, P. Taylor, and R. R. da Silva, "Usability of a virtual coach system for therapeutic exercise for osteoarthritis of the knee,"

[65] S. Tobis, J. Piasek, M. Cylkowska-Nowak, and A. Suwalska, "Robots in eldercare: how does a real-world interaction with the machine influence the perceptions of older people?," *Sensors*, vol. 22, no. 5, p. 1717, 2022.

[66] C. Huisman and H. Kort, "Two-year use of care robot zora in dutch nursing homes: An evaluation study," in *Healthcare*, vol. 7, p. 31, MDPI, 2019.

[67] S. Toyama, F. Ikeda, and T. Yasaka, "Sports training support method by self-coaching with humanoid robot," in *Journal of Physics: Conference Series*, vol. 744, p. 012033, IOP Publishing, 2016.

[68] S. Naneva, M. Sarda Gou, T. L. Webb, and T. J. Prescott, "A systematic review of attitudes, anxiety, acceptance, and trust towards social robots," *International Journal of Social Robotics*, vol. 12, no. 6, pp. 1179–1201, 2020.

[69] T. J. Prescott and J. M. Robillard, "Are friends electric? the benefits and risks of human-robot relationships," *Iscience*, vol. 24, no. 1, 2021. doi : 10.1016/j.isci.2020.101993.

[70] A. Teeters, R. El Kaliouby, and R. Picard, "Self-cam: feedback from what would be your social partner," in *ACM SIGGRAPH 2006 Research posters*, pp. 138–es, 2006.

[71] I. Kotsia and I. Pitas, "Facial expression recognition in image sequences using geometric deformation features and support vector machines," *IEEE transactions on image processing*, vol. 16, no. 1, pp. 172–187, 2006.

[72] G. Castellano and P. W. McOwan, "Analysis of affective cues in human-robot interaction: A multi-level approach," in *2009 10th Workshop on Image Analysis for Multimedia Interactive Services*, pp. 258–261, 2009.

[73] S. Michie, C. E. Wood, M. Johnston, C. Abraham, J. Francis, and W. Hardeman, "Behaviour change techniques: the development and evaluation of a taxonomic method for reporting and describing behaviour change interventions (a suite of five studies involving consensus methods, randomised controlled trials and analysis of qualitative data)," *Health technology assessment*, vol. 19, no. 99, pp. 1–188, 2015.

[74] S. Michie, M. Richardson, M. Johnston, C. Abraham, J. Francis, W. Hardeman, M. P. Eccles, J. Cane, and C. E. Wood. The BCT taxonomy developed to have 93 BCTs.

[75] S. Michie, M. Richardson, M. Johnston, C. Abraham, J. Francis, W. Hardeman, M. P. Eccles, J. Cane, and C. E. Wood, "The behavior change technique taxonomy (v1) of 93 hierarchically clustered techniques: Building an international consensus for the reporting of behavior change interventions," *Annals of Behavioral Medicine*, vol. 46, pp. 81–95, 03 2013.

[76] H. Gilchrist, J. S. Oliveira, W. S. Kwok, C. Sherrington, M. B. Pinheiro, A. Bauman, A. Tiedemann, and L. Hassett, "Use of behavior change techniques in physical activity programs and services for older adults: findings from a rapid review," *Annals of Behavioral Medicine*, vol. 58, no. 3, pp. 216–226, 2024.

[77] U. ARNAUTOVSKA, F. O'CALLAGHAN, and K. HAMILTON, "Behaviour change techniques to facilitate physical activity in older adults: what and how," *Ageing and Society*, vol. 38, no. 12, p. 2590–2616, 2018.

[78] R. Y. S. T. Friis Dam. accesed 1st of november 2024.

[79] A. Hudaib, R. Masadeh, M. H. Qasem, A. Alzaqebah, *et al.*, "Requirements prioritization techniques comparison," *Modern Applied Science*, vol. 12, no. 2, p. 62, 2018.

[80] H. Koller;Franz, Burmester;Michael.

[81] M. Hassenzahl, Marc, M. Burmester, Michael, F. Koller, and Franz, "Attrakdiff: Ein fragebogen zur messung wahrgenommener hedonischer und pragmatischer qualität," 01 2003.

[82] I. Díaz-Oreiro, G. López, L. Quesada, and L. A. Guerrero, "Ux evaluation with standardized questionnaires in ubiquitous computing and ambient intelligence: a systematic literature review," *Advances in Human-Computer Interaction*, vol. 2021, no. 1, p. 5518722, 2021.

[83] C. Inniss, "Effects of vinyasa yoga practice on fitness levels of healthy adults," 2012.

[84] J. Nielsen and T. K. Landauer, "A mathematical model of the finding of usability problems," in *Proceedings of the INTERACT '93 and CHI '93 Conference on Human Factors in Computing Systems*, CHI '93, (New York, NY, USA), p. 206–213, Association for Computing Machinery, 1993.

11 Appendix

Appendix A The semi-structured interview questions with the experts.

First the concept of a social robot was explained to the experts after which all three social robots were introduced to the experts. Then the following questions were posed:

1. What is your first impression of these three ideas?
2. Is there one of these three which you prefer? Why is that?
3. Is there one you would use yourself?
4. Which one would fit best for users with KOA?
5. Wat are additions and or changes you would make to these robots?
6. What is the most important part of this robot to keep?
7. Do you think that integrating ideas might work? Which ones then?

Appendix B Full knee osteoarthritis exercise sheet

Oefeningen voor mensen met knieartrose

ARTROSE GEZOND

- Met deze oefeningen verbetert u de spierkracht van uw benen.
- Als u deze oefeningen 3 tot 5x per week doet, kan dit uw klachten verlichten.

Oefening 1

1. Ga zitten op een rechte stoel. ***(Zie plaatje 1)***
2. Strek één been naar voren, waarbij uw voet van de grond komt en houd dit 10 seconden vast. ***(Zie plaatje 2)***
3. Laat uw been daarna langzaam zakken en herhaal de oefening met uw andere been. Begin met 5 keer met elk been en herhaal de oefening elke week iets vaker totdat u de oefening gemakkelijk 10 tot 15 keer met elk been kunt doen.

Oefening 2

1. Ga op de rand van een rechte stoel zitten en zet uw benen iets uit elkaar. ***(Zie plaatje 1)***
2. Strek uw armen naar voren en sta langzaam op totdat u helemaal rechtop staat. ***(Zie plaatje 2)***
3. Houd uw armen naar voren en ga weer langzaam zitten.
4. Herhaal de oefening. Begin met 5 keer en herhaal de oefening elke week iets vaker totdat u de oefening gemakkelijk 10 tot 15 keer kunt doen.

Oefening 3

1. Ga liggen op de vloer of op een stevig bed, met een opgerolde handdoek onder uw knieën. ***(Zie plaatje 1)***
2. Strek één been naar voren, waarbij de hiel omhoog komt, en houd dit 3 seconden vast. ***(Zie plaatje 2)***
3. Laat uw been daarna langzaam zakken en herhaal de oefening met uw andere been.
4. Begin met 5 keer met elk been en herhaal de oefening elke week iets vaker totdat u de oefening gemakkelijk 10 tot 15 keer met elk been kunt doen.

Figure 29: *The full exercise sheet of which the exercises were taken and shown in 5[6]*

Appendix C All dialog texts found in the health dialog part of the prototype.

“Hallo, mijn naam is NAO! Ik ga u helpen met actief blijven.”

“Laten we het eerst eens over uw fysieke gezondheid hebben. Ik ga u een serie van ja of nee vragen stellen. Dan gebaseerd op uw antwoorden kan ik een advies geven over wat voor beweging u zou kunnen doen vandaag. Het is belangrijk dat u luid antwoord want soms heb ik moeite met dingen verstaan”

“Heeft u gister meer dan 7000 stappen gezet? Of een andere vorm van sport gedaan?”

“U houdt een goeie activiteit aan! Top!”

“Oke, goed om te weten”

“Doet uw knie gewricht vandaag pijn?”

“Hoe zou u deze pijn beschrijven op een schaal van 1 tot 10? 1 is geen pijn en 10 de ergste pijn die u ooit heeft gevoeld”

“Dat is goed om te horen!”

“Oh dat is vervelend”

“Is het gewricht ontstoken? Dit kunt u checken door het aan te raken en te voelen of het opgezwollen of warm is.”

“Is het gewricht ontstoken?”

“Omdat u aangeeft beide pijn en ontsteking te hebben is het belangrijk om uw gewricht te gebruiken maar niet te veel. Laten we samen wat lichaamsgewicht oefeningen doen, die zullen hopelijk helpen.”

“U geeft aan dat uw gewricht ontstoken voelt, ik stel voor dat we samen wat yoga doen om de stijfheid wat te verminderen”

“U geeft aan pijn te hebben maar geen onsteking, laten we dan beide yoga en lichaamsgewicht oefeningen doen om die pijn wat te verminderen”

“Het lijkt er op dat uw gewricht er goed voor staat, laten we samen wat lichaamsgewicht oefeningen doen om dat zo te houden!”

“Dat is fijn”

“Het lijkt goed te gaan met uw gewricht, aangezien u niet zoveel heeft gelopen of gesport stel ik voor dat u op een wandeling gaat of een andere vorm van sport, zoals zwemmen of fietsen gaat zodat u dat gewricht comfortabel houdt”

Appendix D   The code used to make NAO work

https://github.com/soezoenoe/KOA_CODE

Appendix E The information letter given to testers prior to testing

Informatie brief

Beste deelnemer,

Ik heb een prototype ontwikkeld die kan helpen bij een gezonde en veilige manier van actief blijven voor mensen met (knie) artrose. Dit prototype is speciaal ontwikkeld voor mensen die moeite hebben met inschatten hoe en wanneer ze veilig kunnen bewegen. Tijdens dit onderzoek is het doel om uw mening van het prototype te vinden en te vinden of het fijn is in gebruik voor u.

Tijdens het testen kunt u helaas geen volledig beeld krijgen van waar en wanneer de robot wordt gebruikt. Daarom schetsen we de gebruiks situatie voor u in deze brief:

NAO is een robot die bij u in huis staat, hij is speciaal ontwikkeld om steun te bieden tijdens een sport activiteit. Dagelijks kunt u hem aan zetten om same door te gaan hoe u zich voelt, hij stelt een aantal vragen en biedt u dan advies over wat voor sport activiteit u kunt doen om uw (knie) gewricht zo comfortabel mogelijk te houden. Afhankelijk van het advies dat hij u geeft kunt u bepalen of u er voor open staat om die vorm van sport uit te voeren. Als u aangeeft veel last te hebben van uw gewricht stelt hij misschien voor om toch even lichte beweging te doen omdat dit toch wel echt kan helpen bij het verminderen van de klachten. Natuurlijk kunt u ook bepalen om zelf een sport activiteit uit te kiezen en die samen met NAO te doen. Verder zou NAO u verschillende bewegings routines leren en vooral ook leren herkennen wanneer u bepaalde routines het beste zou kunnen uitvoeren. Over de loop van een half jaar zou u dan leren zelf in te schatten wanneer welke vorm van beweging een comfortabel gewricht opleverd voor u.

Wat houdt dit onderzoek in voor u?

Het onderzoek bestaat uit een paar onderdelen:

- Ik leg u drie verschillende activiteiten die u met NAO kan uitvoeren uit. Vervolgens gaat u deze drie activiteiten doorlopen met de robot. Zo een activiteit is bijvoorbeeld het bespreken van uw fysieke gezondheid met de robot.
- Na het uitproberen van het prototype wordt u gevraagd om een vragenlijst in te vullen. Hier in krijgt u een paar vragen over leeftijd, gender en of u wel of niet artrose heeft. Verder krijgt u een vragenlijst genaam AttrakDiff hierbij kiest u uit twee woorden welke het beste uw ervaring met de robot omschrijft.
- Ten slotten lopen we een kort interview door waar u nog wat vragen gesteld worden en u verder kan uibreiden op uw ervaring. Hiervan wordt de audio opgenomen.

Het is belangrijk dat u weet dat de adviezen die de robot geeft niet als medisch advies genomen mogen of kunnen worden. Als u goed advies wilt over gezonde beweging moet u contact opnemen met uw gezondheidszorgers zoals de huisarts of fysiotherapeut.

Zijn er nadelen voor u door mee te doen aan dit onderzoek?
Nee, dit onderzoek is doorgenomen door de etische commissie van de universiteit twente, specifiek de commissie van computer en informatiewetenschappen (CIS). Verder bent u natuurlijk altijd vrij om te stoppen met de test of om een vraag/vragen niet te beantwoorden. Hier zitten geen gevolgen aan vast.

Wat gebeurt er met uw gegevens?

Uw naam en de audio opname van het interview worden opgeslagen, op zijn laatst tot 31 januari. Uw naam wordt los van de stem opname opgeslagen door middel van het ondertekende toestemmingsformulier. Uit de stem opnamen, die opgenomen wordt tijdens het interview, wordt informatie gehaald die vervolgens in het verslag gebruikt wordt. Sommige dingen die u zegt zouden anoniek gequote kunnen worden in het verslag, uw naam zal er niet bij vermeld staan. Verder wordt er ook naar uw leeftijd, gender, en artrose vorm gevraagd. Dit wordt gebruikt om een beeld te geven over voorkeur/meningen per leeftijds groep en gender.

Contact informatie:

Onderzoeker:
Suzanne Rutten : s.w.h.rutten@student.utwente.nl

Ethische commissie:

ethicscommittee-CIS@utwente.nl

Als u vragen heeft kunt u deze altijd aan de onderzoeker stellen. Mocht u vragen over uw rechten hebben of vragen die u niet kwijt wil bij de onderzoeker kunt u altijd de ethische commissie een mail sturen.

Appendix F The consent form used for testing

Toestemmingsformulier voor gebruikerstesten ter ondersteuning van sociale robots voor het beperken van pijn symptomen van artrose door middel van beweging

U KRIJGT EEN KOPIE VAN DIT GEÏNFORMEERDE TOESTEMMINGSFORMULIER

Dit afstudeerproject van de studie Creative Technology heeft als doel een ondersteunende sociale robot te ontwerpen voor zelfmanagement van knie artrose pijn door begeleide beweging met behulp van de robot. De sociale robot is bedoeld om mensen te ondersteunen bij het uitvoeren van bepaalde bewegings en sport activiteiten, zo geeft hij ook advies over wat voor beweging de gebruiker kan doen. Tijdens deze test worden verschillende aspecten van de sociale robot getest. Daarna wordt een korte vragenlijst gevolgd door een interview afgenomen om de aantrekkelijkheid en bruikbaarheid van de interventie te beoordelen. De hele test, vragenlijst, en interview duren maximaal 30 minuten.

Er worden geen persoonlijke gegevens van de deelnemers verzameld tijdens het interview. Als de proefpersoon toestemming geeft voor een audio-opname, wordt deze na analyse van de informatie vernietigd.

Bedankt voor uw medewerking en tijd.

Vink de juiste vakjes aan

	Ja	Nee
Deelname aan het onderzoek		
Ik heb de studie-informatie d.d. [15/1/2025] gelezen en begrepen, of deze is aan mij voorgelezen. Ik heb vragen over de studie kunnen stellen en mijn vragen zijn naar tevredenheid beantwoord.	○	○
Ik geef vrijwillig toestemming om deel te nemen aan dit onderzoek en begrijp dat ik kan weigeren om vragen te beantwoorden en dat ik mij op elk moment kan terugtrekken uit het onderzoek, zonder dat ik daarvoor een reden hoef op te geven.	○	○
Ik begrijp dat deelname aan het onderzoek een observatie van verschillende taken uitvoeren, een vragenlijst invullen, en een interview inhoudt.	○	○
Gebruik van de informatie in de studie		
Ik begrijp dat de informatie die ik verstrek, gebruikt zal worden voor de evaluatie van een prototype dat beschreven staat in een afstudeerproject verslag.	○	○
Ik begrijp dat persoonlijke informatie die over mij wordt verzameld en waarmee ik kan worden geïdentificeerd, zoals [bijv. mijn naam of waar ik woon], niet buiten het onderzoeksteam zal worden gedeeld.	○	○
Ik ga akkoord met het gezamenlijke auteursrecht van de vragenlijst en interview aan Suzanne Rutten	○	○
Ik ga ermee akkoord dat mijn informatie gedeeld kan worden met andere onderzoekers voor toekomstige onderzoeken die vergelijkbaar kunnen zijn met deze studie. De informatie die gedeeld wordt met andere onderzoekers zal geen informatie bevatten die mij direct kan identificeren. Onderzoekers zullen mij niet contacteren voor aanvullende toestemming om deze informatie te gebruiken.	○	○

Handtekeningen

______________________	______________________	________
Naam van de deelnemer	Handtekening	Datum

Ik heb het informatieblad nauwkeurig voorgelezen aan de potentiële deelnemer en heb er, voor zover ik kon, voor gezorgd dat de deelnemer begrijpt waarvoor hij/zij vrijwillig toestemming geeft.

Suzanne Rutten ________

Onderzoekers naam Handtekening Datum

Study contact details voor verdere informatie:

s.w.h.rutten@student.utwente.nl

Contactgegevens voor vragen over uw rechten als onderzoeksdeelnemer

Als u vragen hebt over uw rechten als onderzoeksdeelnemer of informatie wilt verkrijgen, vragen wilt stellen of zorgen over deze studie wilt bespreken met iemand anders dan de onderzoeker(s), neem dan contact op met de secretaris van de Ethische Commissie/domein Computer & Informatiewetenschappen aan de Universiteit Twente via ethicscommitteecis@utwente.nl

Appendix G The Attrakdiff questionnaire

AttrakDiff: Vragenlijst

Auteurs: Prof. Dr. Michael Burmester, Prof. Dr. Marc Hassenzahl &
Franz Koller

Datum: Juni 22, 2011
Vertaald door Suzanne Rutten op 7 juni 2025

Uw mening

In dit bestand vindt u woord paren die u helpen bij het evalueren van het product dat u net hebt leren kennen. Deze woord paren stellen twee extreem tegenovergestelden voor, hier tussen bevinden zich 7 graden.

Een voorbeeld:

slecht ☐ ☐ ☐ ☐ ☒ ☐ ☐ goed

De bovenstaande beoordeling sugereert dat u het product grotendeels goed vindt maar dat er wel verbetering mogelijk is

Denk niet te lang na over uw antwoorden, vul uw eerste ingeving in.

Het kan dat sommige evaluerings woorden niet helemaal bij het product passen. Toch is het belangrijk dat u wat invult op de Schaal. Houdt er rekening mee dat er Geen goede of foute antwoorden mogelijk zijn, alleen uw mening is hier van belang!

hello, technology UID

Geef alstublieft uw indrukken van het product door op de Schaal aan te vinken wat uw indruk was per regel.

	1	2	3	4	5	6	7	
Menselijk								Technisch
Isolerend								Verbindend
prettig								onprettig
innovatief								conventioneel
simpel								ingewikkeld
professioneel								onprofessioneel
lelijk								mooi
praktisch								Niet praktisch
sympathiek								Niet sympathiek
moeizaam								eenvoudig
stijlvol								kitsch
voorspelbaar								onvoorspelbaar
goedkoop								kwalitatief
buitensluitend								betrekkend
Brengt me Dichter bij anderen								Trekt me verder weg van anderen
Niet presenteerbaar								presenteerbaar
afwijzend								uitnodigend
Niet creatief								creatief
goed								slecht
verwarrend								duidelijk
afstotend								aantrekkend
uitgesproken								voorzichtig
innovatief								conservatief
saai								intrigerend
Niets vragend								uitdagend
motiverend								ontmoedigend
nieuw								alledaags
onmanagebaar								managebaar

Appendix H Semi-structured interviews during testing

- Wat vindt u van de robot?
- Bracht de robot u een toegevoegde waarde met het idee van bewegen in uw achterhoofd?
- Wat zou u aanpassen aan de robot? Als u alles zou mogen aanpassen?
- Zou u hem zelf gebruiken? Waarom wel of niet?
- Als niet, zijn er aanpassingen waardoor u hem wel zou gebruiken?
- Als wel, zou u hem aanraden aan iemand anders?
- Waar zou u de robot neer zetten in uw huis?
- Wat vondt u van de teksten die NAO uitsprak?
- Snapt u waarom u dit advise kreeg voor bewegings soort?
- Voorkeur voor een van de bewegings dingen?

Appendix I The summaries of all 8 semi structured interviews

Summaries of all 8 interviews with relevant quotes

Participant 1

Robot appearance

The knees were confusing, where they are on the robot. Would want the robot to be more human like.

Robot speech

Felt like she understood all the crucial information

Did not understand why she got the advice she did during the health dialog.

Thinks the pain scale might not make sense as she said her pain was an 8 out of 10 and still had to exercise.

Robot placement

Maybe in the living room, because when you're not using it you would have to put it away and that would hurt your knees.

Robot exercise

Thought the yoga was a lot, forgot that the robot told her not to overdo it and thought she might have overdone the movement. She would prefer the robot explained the exercise prior to starting the movement. However, as the robot was showing the movement that way she felt she had to.

Participant 2

Robot appearance

The robot is pretty cute, really likes how it is a physical robot, thinks this can be more motivating than for example a video guide.

Robot speech

He speaks pretty quickly, and sometimes pronounces things weird. Which can be confusing. He speaks in a polite manner and has good grammar, which Is nice. The voice does sound very robotic, like google translate, would like the addition of a human voice

Robot placement

Thinks that the placement of the robot in the house in and of itself is of value, as just seeing the robot serves as a reminder to exercise. Would place the robot on an elevated surface like a chest of drawers.

Robot exercise

Really likes how the robot demonstrates how you should do the yoga routine, Thinks as the guided exercise is quite simple it doesn't need to be demonstrated. Prefers the yoga routine as the robot moves with you. Does think that the harder the guided exercise gets the more demonstration of said exercise by the robot is of value.

Other comments

The functionality is good *: "Qua functionaliteit, dat zit goed!"*

Would not necessarily use the robot himself, prefers doing his own exercise. Can imagine that when its colder outside, for people with arthritis, it would be very nice for them.

Would add customization of the robot, like its appearance.

Participant 3

Robot appearance

The robot looks cool.

Robot speech

Thinks the questions posed by the robot were clear, also thinks the advice provided by the robot made sense as it explained the decision. Would like the robot to understand more, and maybe indicate when it is starting to listen to you, as sometimes she wanted to speak but the robot paused before continuing.

Robot placement

She would put it somewhere on the floor and otherwise put him away in a closet.

Robot exercise

Likes how the robot provides tips during the exercise routines. Also likes the advice on how to improve her form for the guided exercise. Really liked its motivation during exercise

Other comments

She does stretch erxercises and would like to use nao for said exercises :*"Ja ik vind het best wel leuk, ik zou hem morgen voor mijn stretch oefeningen gebruiken"*

Would be even more likely to use the robot if you could implement your own exercise routine, for example her stretch routine.

She would recommend him to others if his understanding of speech was broader.

Participant 4

Robot appearance

Not such a fan of the robots appearance

Robot speech

Sometimes didn't fully understand an exercise as it was explained by the robot, did say he could have misheard, but was left with some questions. Specifically, the exercise where the user has to lift their leg while their leg is still on the towel was confusing to him. He would like to be able to ask for clarification. Fully understood the explanation and reasoning of why certain exercise was advised by the robot.

Robot placement

In the living room but it is a bit crowded there.

Robot exercise

The exercises were a bit quick for his liking (when talking about yoga) He would also prefer the addition of a count down by the robot when you are performing exercises for a certain time. :*" aangeven van wanneer het is en helemaal de 10 seconden met je been omhoog houden, dat hij gewoon zelf automatisch aan zou geven van oh ja, je hebt nu 10 seconden, switch van been*."

Prefers the yoga, as he prefers seeing how to do an exercise over hearing it.

Other comments
Thinks the process of registering movement might be slow in the robot, but aside from that it's a fine guide.
Isn't sure if you can over exert your self as the robot doesn't have a skip or stop function as of now.

Would be open to using the robot if the adjustments mentioned above were implemented. Especially as he likes how the robot figures it out for you, how you are doing on the exercise.

Participant 5

Robot appearance

It's a fun little thing, does seem slightly helpless like it might fall over.

Robot speech

Would like the robot to be able to understand more, not just yes or no. So you can have a full conversation. For example during exercise that you can just have a conversation. Sometimes got confused by instructions provided by the robot. Thinks he understood the advice provided by the robot but can not be sure.

Robot placement

Not relevant as he wouldn't use the robot himself.

Robot exercise

Has no preference for either type of exercise implementation, likes both equally. Does think the exercise coach might be more useful: *"nuttiger, want dan heb je echt een soort van personal trainer-achtig idee."*

Other comments

Thinks it better than an app. He himself doesn't struggle with exercise motivation and knows what he is doing so he wouldn't use the robot himself. However, might be useful to others. He would recommend it with the idea of can improve the enjoyment of exercise but he doesn't believe this will fix a persons motivation. If they don't want to do it they won't.

Would like if the robot were to walk around, as he likes the movements the robot does while its speaking.

Participant 6

Robot appearance

Really likes robots appearance: *“Op eerste gezicht vind ik hem heel schattig, dus ik ben intrigued om er samen mee te gaan[...] Ik ben gewoon benieuwd wat het gaat doen.”*

Robot speech

Really likes the way the robot speaks, thinks it is quite human and likes that it has a higher pitch. It is a bit quick but, with the addition of the robot repeating it self as a feature, she doesn’t mind. The text spoken by NAO was very clear. If you listen the exercises are very doable. Fully understood the advice provided by the robot on why and what type of exercise she should do.

Robot placement

In the living room as there is space there.

Robot exercise

She does physio therapy and doesn’t always do the exercises so she wouldn’t be sure if she would with the robot. However if she (the robot) came up to her and said lets do some exercise she (participant) would do the exercise. Prefers the guided exercise coach as that was less hard for her and it took less time.

Other comments

Wouldn’t use the robot due to lack of time however: *“Indien ik er tijd voor zou hebben en ik zou het in mijn huis hebben en ik verveel me, zou ik hem zeker aanzetten.”*

Would recommend the robot to someone else, especially if she sees them struggling. As it is a cute and fun solution.

Added voice recognition so you can ask the robot to repeat itself.

Participant 7

Robot appearance

Cool

Robot speech

Would like the robot to have a repeat yourself command. Sometimes the speech was very clear and other times it would pronounce words in a weird and confusing way. Adding a real human voice would help. Which would help with feeling empathy for the robot. Really understood and liked the way in which the robot adviced on what and why exercise should be done.

Robot placement

In her bedroom probably.

Robot exercise

Would like the robot to indicate that it sees her, she would like more feedback. Also thinks especially older people would need more feedback. Preferred the exercise with feedback on her form.

Other comments

Would use the robot herself as she struggles keeping consistent with exercises, both in doing them and in the form, and the robot is really clear in what you are supposed to do. She also wouldn't do exercise without the robot, on her phone apps she doesn't use those: *"Zonder die robot zou ik dat niet doen."*

Thinks the robot has added value as it draws attention by movingand likes its movement and interaction :*" Dus ook wel dat hij echt een beetje als een mens beweegt en dat hij echt met je praat, dat voelt wel fijn."*

Would recommend the robot but on the condition that it provides more feedback, and more motivation like it already has.

Would like the robot to be almost a personal assistant, or if it could help with movements for other joints affected.

The robot seemed motivation oriented: "Hij is wel erg op motivatie gericht dat je toch wel iets doet." But could also be implemented as a personal trainer in the gym.

Thinks the addition could be nice but also overwhelming.

Participant 8

Robot appearance

Thinks the robot is cute

Robot speech

Would like to have more speech options with the robot, like a full conversation. Some more clarification is needed for the explained exercises. It was already well explained but could be even better. When doing the dialogue, the robot told her it felt bad for her pain which made her feel supported: "*Toen voelde ik me wel emotioneel geondersteund*."

Robot placement

In her bedroom, as a sort of reminder that she needs to do some exercises everyday.

Robot exercise

Ideally would want the robot to demonstrate, provide feedback on, and explain the exercises the user is supposed to perform. Sometimes she got confused by the lack of visual demonstration. *"Nou, in ieder geval, ik vind dat een cool idee, dat je dus inderdaad kan zien wat die persoon verkeerd doet en dat die dan daar weer feedback op geeft."* Would like the addition of more feedback, when to start an exercise and when to switch etc.

Other comments

Thinks for stakeholders to use this its interaction might need to be even simpeler, maybe just an on and off button and nothing else they have to do.

"Eigenlijk misschien het liefst gewoon alleen aan en uit knoppen."

Would like to use a sort of pay it forward system with the robot, where if she feels she understands the robot she gives it to the next person and so forth.

Thinks the addition of LEDs can make it clearer what joint needs to be moved, for example in the crux of her knee then it might be clearer when that joint is used. That could help with making it intuitive.

Appendix J Word pairs and the resulting average scores for these word pairs.

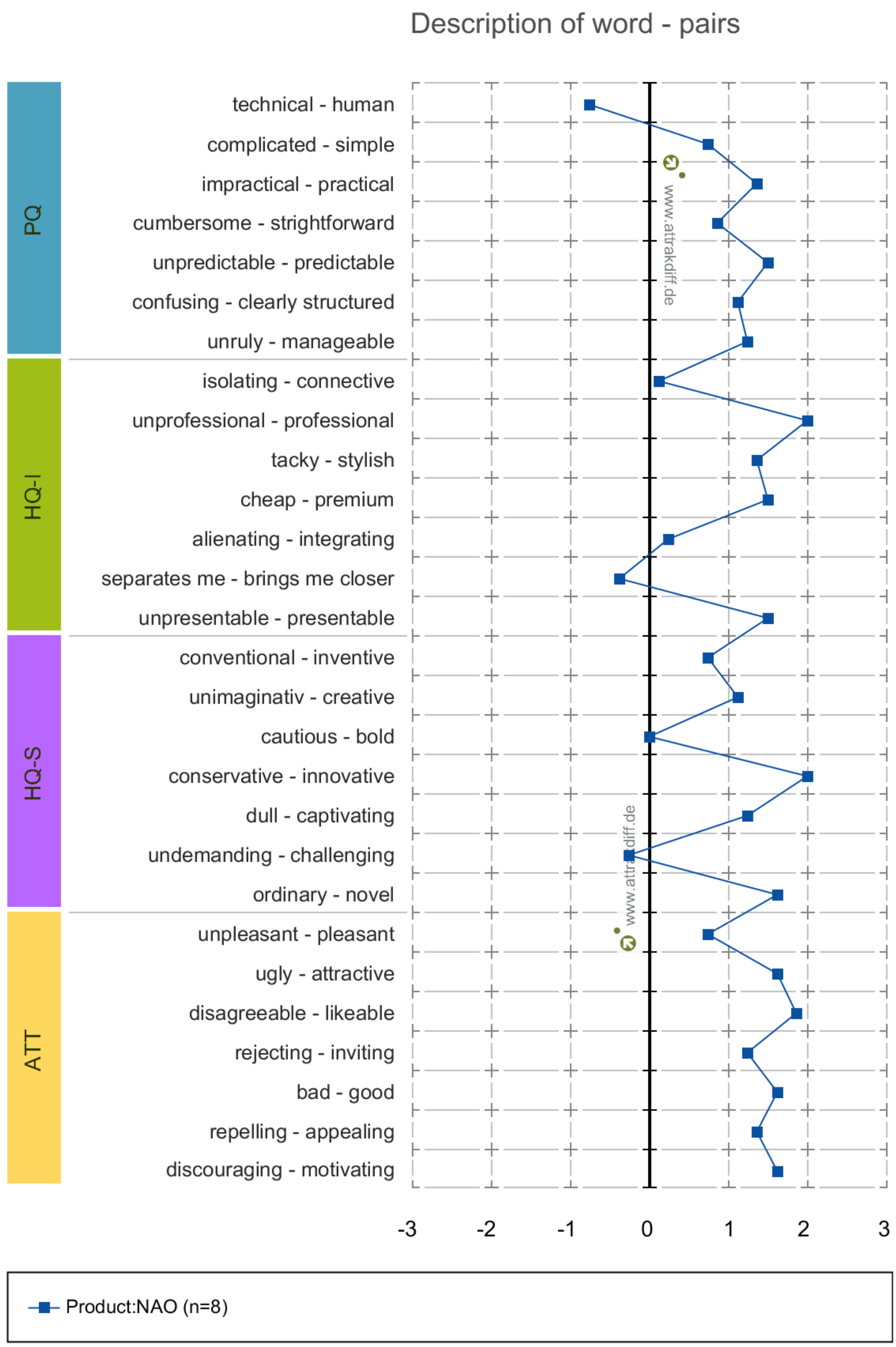


FIGURE 30: *The description of word pairs and their average score divided into the four scales(PQ, HQ-I, HQ-S, and ATT)*