A Digitally-Augmented Ground Space with Timed Visual Cues for Facilitating Forearm Crutches' Mobility

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A Digitally-Augmented Ground Space with Timed Visual Cues for Facilitating Forearm Crutches' Mobility

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Abstract. Persuasive technologies for physical rehabilitation have been proposed in a number of different health interventions such as post-stroke gait rehabilitation. We propose a new persuasive system, called *Augmented Crutches*, aimed at helping people to walk with crutches. People with injuries, or with any sort of mobility problem typically use assistive devices such as crutches, walkers or canes in order to be able to walk more independently. However, walking with crutches is a learning skill that needs continuous repetition and constant attention to detail in order to walk correctly with them and without suffering negative consequences, such as falls or injuries. In close collaboration with therapists, we identify the main issues that patients face when walking with crutches. These vary from person to person, but the most common and hardest challenges are the position and coordination of the crutches. *Augmented Crutches* studies human behavior aspects in these situations and augments the ground space around the user with digital visual cues where timing is the most important factor, without the need for a constant therapist providing manual help. This is performed through a mini-projector connected to a smartphone, worn by the user in a portable, lightweight manner. Our system helps people to learn how to walk using crutches with increased self-confidence and motivation. Additionally, our work identifies timing, controllability and awareness as the key design dimensions for the successful creation of persuasive, interactive experiences for learning how to walk with crutches.

Keywords: Persuasive technologies · Behavior change · Rehabilitation · Augmented experiences · User experience · Interaction design

1 Introduction

The number of people with the need for learning to walk with assistive devices is increasingly rising [1]. Mobility is an important prerequisite for equal participation in social life and satisfaction of basic human needs. Mobility impairments can restrict the participation in social life of those affected such that people lack fair opportunities for fulfilling their needs [20]. Loss of physical mobility makes maximal participation in

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desired activities more difficult and in the worst case fully prevents participation [21] Among those with mobility impairment, the number of people with the need for learning to walk using assistive technology is increasingly rising [3].

Restoration of walking is a primary goal for people with stroke and their therapists. In many cases although the patient can resume walking, he/she has to face restrictions. Few people with stroke are able to mobilize outside the house as they wish, and approximately 20% are unable to get out of the house unaided at all [23]. Another example of physical impairment is Cerebral palsy (CP) which is the most common childhood motor disability and often results in debilitating walking abnormalities, such as flexed-knee and stiff-knee gait.

Current medical and surgical treatments are only partially effective and may cause significant muscle weakness. However, emerging walking technologies can substantially improve gait patterns and promote muscle strength in patients [24]. People with Multiple sclerosis (MS) also experience gait impairments being one of the most common symptoms of the disease [23] and they require training in using walking aids like canes, crutches. These aids are also commonly recommended for balance problems, pain, weakness, joint instability, and to recover locomotion. Many assistive devices can mitigate gait disturbance. However, the most common assistive devices are crutches [1, 19].

The two most common models of crutches are: axillary crutches and forearm crutches, or Lofstrand. Forearm crutches are the dominant type used in Europe, whether one considers them for short- or long-term usage. Crutches help an individual to maintain the balance and can help in the elimination of weight bearing - partially or completely - on the injured leg. Crutch gait patterns include two-points, three-point, four-point, swing-to, and swing-through patterns. Changes from the position of the crutch, and the amount of weight bearing in the injured leg occur according to the crutch gait that depends on the amount of weight that the individual can put on the injured leg [1].

However, the use of this mobility aid can be associated to some negative consequences related to its incorrect use. Walking with crutches requires an understanding of a technique. It is a learning process that needs continuous repetition and constant attention to detail in order to walk correctly with them, not suffering negative consequences, such as falls or other injuries.

Walking with crutches crutches is, in general, a theme about which people have a lot of doubts. Feedback from an instructor can often be useful for walking correctly. Physiotherapists often give instantaneous feedback by gradually correcting the patient's position. However, there is a lack of opportunity for receiving permanent intervention from the physiotherapist leaving patients to rely on themselves for moving using crutches. Moreover, self-confidence can quickly be replaced with anxiety, especially if an accident or injury occurs [19]. In this context, we present Augmented Crutches, a novel system aimed at helping people to walk with crutches. Working in close collaboration with therapists, we identify the main issues that patients face when walking with crutches. These vary from person to person, but the most common and hardest challenges are the position and coordination of the crutches.

In this context, our main research question (RQ) was: *Can a ground-projection mobile system be effective in correctly training people to learn how to walk with crutches?*

A secondary research question (RQ2) was whether such system could increase motivation and self-confidence, since it is a long, repetitive process that requires a lot of motivation and effort.

Augmented Crutches studies human behavior aspects in these situations and augments the space around the user with digital indications where timing is the most important factor, without the need for a constant therapist providing manual help. This is performed through a mini-projector connected to a smartphone, worn by the user in a portable, lightweight manner. This paper presents the interactive design aspects of the system and identifies *timing*, *controllability* and *awareness* as the key design dimensions for the successful creation of interactive experiences for motivating patients and for learning how to walk with crutches.

2 Background and Related Work

Technologies focusing on augmentation have the capability of creating an interactive, motivating environment for patients with mobility impairment in which practice, learning and feedback can be manipulated to create individualized treatments to retrain movement [26].

Many of the technologies focusing on augmentation of the user experience are persuasive by nature. Persuasive technologies for physical rehabilitation have been proposed in a number of different health interventions such as post-stroke gait rehabilitation [13, 18]. For example, Luo et al. [28] developed a training environment that integrates augmented reality (AR) with assistive devices for post-stroke rehabilitation and training.

Cueing is defined as using external temporal or spatial stimuli to facilitate the initiation and continuation of movement (gait) [30], providing the necessary trigger to switch from one movement to other sequences of movements. This could explain why people with Parkinson, in the absence of external cues, show slowed movements and low execution times. These can significantly improve with the use of external cues.

An effective mobility-training program involves the use of external cues. Movement speed (gait speed), and movement length (stride length) have been shown to improve when visual cues or auditory cues are present, improving gait and contributing to a more active and independent life.

There is also indicative evidence in support of the use of verbal instructions (also another kind of cues), to take big steps in walking training for stride length improvement in people with mild to moderate Parkinson's disease who are without cognitive impairment [31].

Auditory signals are a form of rhythmic cues which reportedly also improve gait. Cueing techniques such as musical beats [32, 33], metronomes [32], rhythmic sound [34] or verbal instructions [35] have been implemented to improve gait. Auditory cues have been demonstrated to increase speed gait [33].

Suteerawattananon et al. [35] studied the effect of auditory cues and visual cues and conclude that using metronomes significantly improve gait. Gait speed significantly improve with auditory cues.

Visual cues have been also found to help gait. These cues are since placement of visual floor markers [36], adaptive glasses [37]. Recently, laser guided walking visual cue such as projection of visual cues [29], projection of lines [3], and laser-guided walking canes [40] have been used.

In traditional motor rehabilitation visual cues have normally used of a series of stripes placed on the floor in traverse line for patients walk all over. Floor markers were reported to being effective in improving gait [10].

Some studies found that placing visual cues can effectively in regulation of stride length, improving gait [9, 11] and also that patients retained a positive carryover effect over after the cues being remove [9, 11]

Both visual and auditory cues have highly effective in improving gait walking in persons with Parkinson. However, they have some limitations when used outdoors, such as external noise (auditory cues) and bright areas (visual cues). In this context, researchers started to study the effects of other type of cues: rhythmic somatosensory (vibration). The results from these studies also show they can improve gait and stride length [41].

Some studies were performed to conclude that simultaneous uses of cues do not improve significantly gait more that each one alone [35].

Suteerawattananon et al. [35] show that both visual or auditory cues significantly improve gait performance but each one has a different impact. Gait speed was significantly increases with auditory cues and stride length was effectively influenced by the use of visual cues.

In order to design digitally-augmented crutches, we used textual cues as well as visual cues. Through the application of textual cues within the design of the crutches, users experience memory retrieval which improves their walking performance [2]. Visual cues play an important role in helping patients, as they are self explanatory and facilitate users when remembering their interactions through the use of visual working memory (VWM). In this section, we review current approaches in terms of persuasive systems for rehabilitation processes (Sect. 2.1) and we provide background information on the domain problem: learning to walk with crutches (Sect. 2.2).

2.1 Persuasive Systems for Rehabilitation

Persuasive technologies for physical rehabilitation have been proposed in a number of different health interventions such as post-stroke gait rehabilitation. There are a large number of digital systems for physical rehabilitation [13, 18]. We review the ones that correlate best with our own system, especially in terms of persuasion.

Task guidance is one approach: computers can help users perform better when they use crutches, by showing them how they are performing by visually projecting what the user is doing and receiving guidance about what to do better and which aspects should be improved. For instance, Tsuda et al. [2] created a robot that provides textual cues based on information such as body acceleration. The textual cues are about the walking stride: whether it is short, long or correct. This improves the walking performance because it acts like a memory recall about the task (walking correctly) [2]. In our system, we also decided to include textual cues for the user to know how to walk with crutches and persuade the user towards changing his behavior. Visual cues are also popular, as they are a signal of something or a reminder of something, aiming at being self-explanatory and pre-attentive. Visual elements were used to e.g. improve the walking skills of Parkinson disease patients [3, 4]. LightGuide [5] explored the use of video projections. A projection was made into the user, using his own body as a projection screen. Visual cues were then projected into the user's hand in order to guide him through the movement. Projecting the information directly in the body, helped the user to keep concentrated and not distracted by the external factors [5].

Rehawalk [6] is a rehabilitation system that projects the visual cues (footprints) on a treadmill during the gait training of the patient. Similarly, Slekhavat et al. [7] developed a projection-based approach AR feedback system that shows visual cues and feedback in order to provide an effective understanding of the relationship between body perception and movement kinematics in rehabilitation exercises. The visual cues depend on the type of exercise. If it is a stepping exercise the footprint icons are presented on the surface of the treadmill, if it is an obstacles' exercise the visual obstacles are presented on the treadmill.

These projection-based approaches for gait disorders' training are based on walking on a surface (usually a treadmill). In contrast to this, our approach is suited for gait training with crutches and projects visual cues (footprints and crutches icons) directly on the floor. With this we want to explore how the user reacts to the visual cues and if it helps the user to know how to walk with crutches, becoming more focused in his task. Another advantage of projecting the visual cues on the floor is portability: as long as it is visible (i.e. not hit by direct sunlight), the system can be used anywhere.

Persuasive systems and Behavior Change Support Systems (BCSS) show great potential for improving the efficacy and efficiency of the rehabilitation process. For instance, Van Delden [8] propose movement-based games for gait rehabilitation with personalization based on gait characteristics. In a similar approach to ours, based on digital augmentation of the environment, they used an eight by one-meter pressure sensitive interactive LED floor and developed interactive games to steer different dimensions of people's gait, increase motivation, provide an enjoying experience, and create an additional platform for gait rehabilitation by physical therapists [8].

Kim and Mugisha [9] present a paradigm called "visual feedback distortion" in which they manipulate the visual representation of step length and study whether that distortion influences gait spatial pattern. They concluded that perturbation of visual information about subjects' movement can cause unintentional motor functions. A related approach with ours is presented by Merrett et al. [10], who describe the research and development of an instrumented forearm crutch that was developed to wirelessly and autonomously monitor a patient's weight bearing over the full period of their recovery, including its potential use in a home environment. Initial results highlighted the capability of the instrumented crutch to support physiotherapists and patients in monitoring usage, thus making use of the reflective mind [11] as an approach to consciously motivate the user.

Other persuasive systems worth noting include physical computer games for motivating physical play among the elderly [13], and modular interactive tiles for short-term training of community-dwelling elderly [14, 15].

A virtual environment like the existing ones is not adequate for the specific problem of learning to walking with crutches, since the patient will need to learn how to adapt to the virtual environment itself. Also, solutions like these are obviously not portable, and therefore the patient is limited to using it only in certain cases. Early examples of persuasive technologies argued for Ambient Intelligence for Persuasion (AmI) [12]. Surrounding the user with persuasive technology (in everyday life) opens up the possibility for implementing persuasive interventions just at the right time and in the right place. This is extremely effective for learning crutch walking. Based on this context, our approach provides persuasive and motivational feedback in two different ways: (i) through persuasive sentences as well as information about gait training, and (ii) through carefully-timed visual cues, including the remaining time the patient has to complete each phase of the gait training.

2.2 Walking with Crutches

There are different types of crutches for different situations. Our work focused on forearm crutches, illustrated in Fig. 1, since forearm crutches are the dominant type used in Europe, whether it is for short- or long-term usage. These crutches are indicated for people undergoing rehabilitation of an injury to the lower limb, and are commonly prescribed to enable functional mobility for people with walking problems [2].

Fig. 1. Forearm crutches.

Additionally, there are several different methods for walking with crutches. These depend the on the weight bearing that the patient can put on the injured side. In collaboration with therapists we learned that the more common types of crutch gait used are: (i) three-point gait; (ii) four-point gait; and (iii) single crutch gait. There has to be specific training for each of these three gaits, although the ones that are more challenging are the three- and four-point gaits.

Three-point gait is used when there is inability to discharge the weight in one of the lower limbs [2]. The sequence, is illustrated by Fig. 2: both crutches and the affected leg move forward together, then the other leg moves forward by the patient (voluntarily). This type of gait is employed when the patient has no strength in the injured leg.

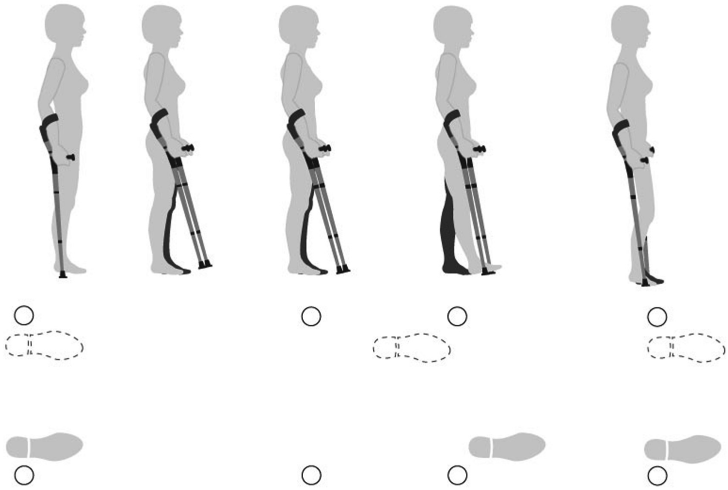

Fig. 2. Three-point gait.

Four-point gait is indicated when the patient is able to put some weight bearing in the injured leg (partial weight bearing) [2]. The sequence, again illustrated (Fig. 3) is the following: right crutch first, then the left foot, then the left crutch, and finally the right foot. This is the sequence for when the injured leg is the left one; if the injured leg is the right one, the crutch that comes first is the opposite of the injured leg.

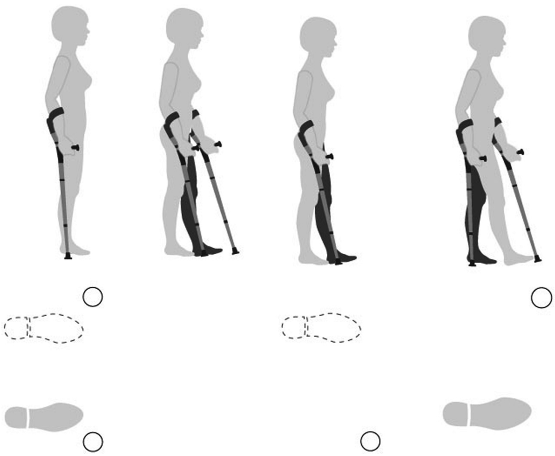

Fig. 3. Four-point gait.

Finally, single crutch gait (Fig. 4). When the weight bearing in the injured leg is 100%. The crutches should be on the arm opposite to the injured leg. For instance, considering the injured leg is the left one, the sequence is the following: the right arm and the crutch move together, with the weaker leg, then the stronger leg moves by itself.

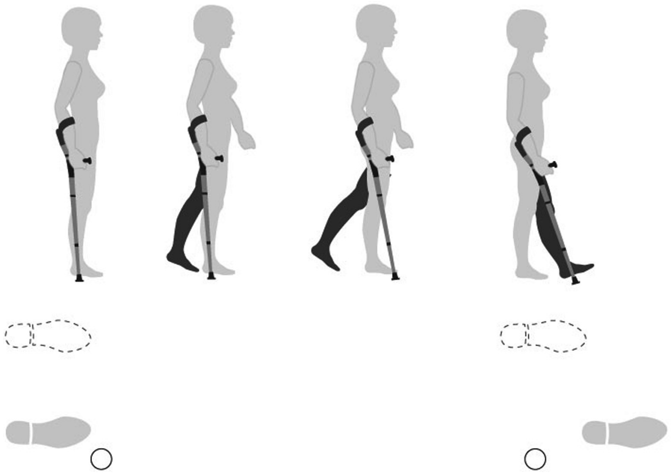

Fig. 4. Single crutch gait.

Many studies of crutch walking have been made by researchers. For example, studies about the amount of weight bearing during crutch walking and studies to improve the user's walking with crutches [1, 17, 18]. However, we could not find any study or device related to crutch gait, i.e. the coordination between the foot step and the crutch, which exhibits changes throughout the rehabilitation process.

We discarded audio cues because of the nature of the learning process itself. Visual cues can help in a more effective way. This is inline current literature that refers e.g. its effectiveness in issues like Parkinson's disease gait training [29].

3 Method

The main challenge that we addressed was the learning of correct positioning and coordination of the crutches. Position and coordination as main challenges were identified through three different sources which we will clarify in the next version of the manuscript: (i) known literature, e.g. [1–3]; This literature includes illustrated manuals of nursing practice as well, which document the problem in a very clear manner[1]; (ii) extensive interviews which were made to experienced physical therapists,

[1] See e.g. *Illustrated Manual of Nursing Practice*, Springhouse Ed., 3rd ed, ISBN-10 1582550824.

who all independently agreed as to the reasons that actually make it difficult for people to learn how to walk with crutches (again, position and coordination); and finally (iii) the first author's own personal experience as a chronic user of crutches. This is also inferred from simple consultation to different specialized websites that provide advice on how to safely and efficiently walk with crutches, as position and coordination are evident as most common problem, and credible websites such as the American Academy of Orthopedic Surgeons (AAOS). In this section, we describe our method, which involved designing the system with the help of experienced therapists, developing in an agile way [27], then evaluating it with a representative sample of target users, and finally discussing the clustered qualitative results.

An ideal system for ambulation rehabilitation should be compact, modular, flexible, versatile, easy to use, easy to switch on and off, friendly to both categories of users (physical therapists and people with ambulation-related disabilities) through the adequate interfaces [16, 22]. It should be a portable, high-usability tool, able to provide training, assistance (adapted to the user's limitations and to the objective of the training program), challenges, constraints, drive and support (Table 1).

Table 1. Relationship between design goals and visual cues.

Design goals	Visual cues	Rationale
Good visibility	Designed as bright white visual cues imposed over a black background	The system should be used in a variety of ground spaces. Therefore, having clean, bright visual cues is paramount to achieve this goal
Well-timed animations	Designed and thoroughly tested with experienced therapists so that they would match the real life training process	Timing is important when helping users to walk with crutches
Improved motivation	Persuasive textual cues	Learning to walk with crutches is typically performed under stressful conditions as the patients need extrinsic motivation in order to succeed. Cues should be designed in order to improve motivation

Other design goals include a precise and real-time diagnosis, evaluation and assessment and to become a biofeedback tool that is persuasive, comprehensible and comprehensive in real-time [16, 39].

Current VR solutions require the use of special equipment that is simply too costly (e.g. VR CAVEs) or too cumbersome to use with crutches (e.g. HMDs). All these alternative techniques were found to be confusing, including from the first author's own personal experience as well as from the user research we performed. We are striving for portability and effectiveness. Interviews with therapists (corroborated by other sources of research such as user observations), clearly point out that people need to train their crutch-walking alone, ideally *anytime*, *anywhere*. The goal is not to replace the physical therapist, but rather have a cost-effective, portable solution that addresses the real needs of people who unfortunately need to learn how to walk with crutches. The visual cues were designed having in mind the crutch-walk learning process. They were validated by the therapists and then we proceeded to evaluate them in the context of the ground-projection system.

Having some of these goals in mind, Augmented Crutches was designed and developed as a projection-based system for assisting the user who is learning how to walk with crutches. All current projection-based approaches for gait training disorders are based on walking on a surface (usually a treadmill). In contrast, our solution projects visual cues (footprints and icons) directly into the floor, augmenting the physical space surrounding the crutches. It presents the user with digital feedback, precisely-timed cues and motivating elements like textual quotes. Figure 5 illustrates the system in use.

Augmented Crutches is worn as a belt that contains a front pocket where a Philips PicoPix mini-projector is connected to an Android phone running the system. This setup allows for portability and avoids the complicated task of VR treadmills, which would require additional training and would confuse learners or even people with significant crutch-walking experience.

Fig. 5. Augmented Crutches.

To provide guidance when walking with crutches, the visual cues need to convey a sense of where to start and *what goes first, the foot or the crutch?* Users are motivated by the combination of what is projected on the floor (the visual cues) with the timed challenge of moving along a path, thus correctly performing a training session.

The design considerations that were addressed included personalization, timing, visual cues and feedback.

Personalization. As described in Sect. 2.2, there are different types of gait training with crutches. Through close collaboration with physical therapists, we designed Augmented Crutches as a solution to address the main three different gait training types: three-point gait, four-point gait and single crutch gait. Personalization provides a gait training adapted to the condition of the patient through a questionnaire that is available in the mobile application. The questionnaire's results perform a triage and sets the system accordingly. Through the user's answers about his physical condition, the system generates the adequate gait training. The questions include: "Which one is the injured side?", "What is the amount of weight that can be put in the injured leg?", age, height, and others.

Visual Cues. The visual cues provide information about the position of the foot and the crutch, as well as the sequence of movements. With this visual guide, the user improves the performance on the correct gait training.

Timing. In our design there is a system-imposed timing, as users follow the visual cues (footprints and the crutches' icons) which are displayed at specified speeds. The user can observe how much time there is to conclude a sequence of the gait training before changing to a new sequence, and can also be more aware about the time that was spent performing any given training sequence.

Feedback. Feedback components provide information about the gait training. This feedback can appear after finishing a sequence of visual cues transmitting to the user a sense of continuation (ex: motivational messages to continue the effort). This feedback can also help the user about the progress of the gait training sessions, again without the need for a human intervention.

Figure 6 illustrates a particular gait training sequence (in this case, for three-point gait).

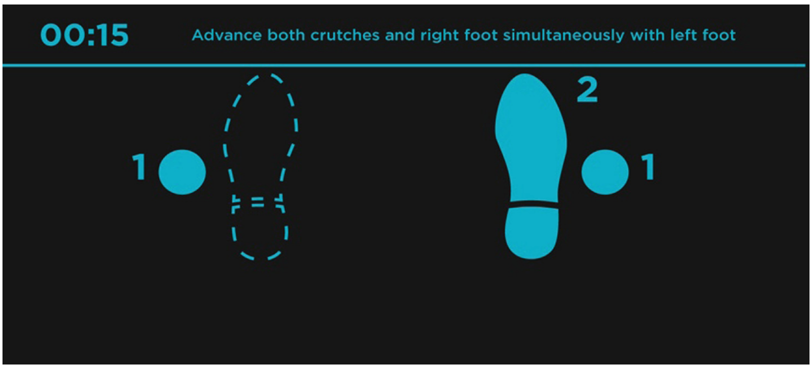

Fig. 6. Augmented crutches showing a sequence of gait training.

3.1 Participants and Procedure

The focus of our evaluation was on understanding the user's behavior regarding the visual cues during the gait training process. We recruited 21 participants (7 who walked with crutches and 14 who never walked with crutches). We made sure that the participants were not visually-impaired, and only participants with normal visual performance were included in the study. Ages ranged from 18 to 56 years old. It is important to point out that the evaluation was documented with informed consent and all image rights belong to the authors.

The following table characterizes the participants in detail (Table 2).

Table 2. Participants' chacteristics.

Subject	Gender	Age	Experience on walking with crutches
U1	F	21	Yes
U2	M	55	Yes
U3	F	56	Yes
U4	M	23	No
U5	F	30	No
U6	F	23	Yes
U7	F	27	Yes
U8	F	44	Yes
U9	F	22	Yes
U10	F	23	No
U11	F	23	No
U12	F	54	No
U13	F	27	No
U14	F	19	No
U15	F	24	No
U16	F	30	No
U17	F	24	No
U18	M	26	No
U19	F	19	No
U20	M	25	No
U21	M	22	No

3.2 Procedure

Each participant was asked to answer the system's built-in questionnaire. The participants that already used crutches were asked to remember the moment that they started using crutches. For the remaining participants, we asked them to imagine that they have an injury and that they have to use crutches without having been taught on how to do it. The questionnaire was deemed very easy to understand by all participants.

The second task, performed by all participants, was to experiment with the system and follow the visual cues (essentially the footprint and the crutch icon as exemplified in Fig. 5). The first sequence of visual cues was shown for 15 s before changing to the next one. Participants could understand and follow the visual cues.

Users were interviewed after each session, and filled-in a small questionnaire. An observer (first author) took notes. The main criteria for the questionnaire's design was: (i) the understanding of the visual cues, (ii) why was this understanding effective or not, and (iii) what was the participant's opinion regarding the timing of visual cues in our system. Focusing the questions on the "why" helped us assess exactly what had been learned by the users, in terms of crutch walking. All data was triangulated between the different sources, so that the researchers' observations were found consistent with the participants' answers in the questionnaires.

With the data collected and clustered, we analyzed the three main issues that arise when designing behavior change support systems for gait training sessions, described in the following section.

4 Results and Discussion

4.1 Qualitative Results

Most users involved in this qualitative study were quite interested in the walking process and noted the importance that our system brings in terms of awareness, e.g. "*This is useful for understanding the crutch walking process*" (U7). There were some general, broad issues that were pointed out. For instance, some users mentioned difficulty using the crutches for the first time, especially during the beginning of the training process: "*I was not sure if the length of my step was correct, besides that I had to memorize the instructions because once I moved the foot, the positioning of the image changed*" (U5, U8).

In terms of feedback, we observed that during the display of visual cues (footprint and crutches icons) which build the gait training, all users were able to understand the visual cues and the position of them, but they often expressed some frustration with the time. As one participant expressed: "*It is too fast, it requires some speed to perform the position of the visual cues*" (U9). Users also noted some lack of explanation regarding the type of crutch that the users have to use in order to perform the training. As one user explained, "*I didn't understand clearly through the image what was the type of crutch that is required*". The problem here is if the user doesn't employ a forearm crutch (Fig. 1), then the gait training supplied by the system will be not adequate.

Users reported high levels of motivation, however this is somewhat expected due to the novelty effect of the system. We were not focused on measuring motivation, but rather making sure that users were engaged and felt motivated. The system showed motivational messages, such as the one illustrated in Fig. 7. With this feedback, we decided to improve our approach by providing more time in each sequence of the visual cues, and also to explain in the beginning which is the type of crutch that the user needs to have.

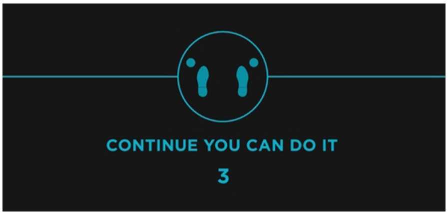

Fig. 7. Augmented crutches' motivating visual cue (an example).

With the data collected and clustered, we analyzed the three main issues that arise when designing behavior change support systems for gait training sessions. We discuss the main takeaways in terms of (i) timing, (ii) controllability, and (iii) awareness.

4.2 Timing

Timing was clearly the most important design dimension for this type of system. Independently of the persuasive icons, textual or visual cues can only be effective if they are displayed at the proper timing.

The stipulated time aimed at helping people improve their locomotion (walking properly with crutches) and not their speed. The "*timer also aims to encourage the person to learn to walk better with crutches*" (U9[2]). Other users are also inline with this motivating capability provided by the well-timed cues. For instance, U8 referred that "*Regarding the timer, in my case I would set it faster, so I did not have to wait for the rest of the time to continue. But time will depend from person to person to people who make faster slow others*" (U8). Also, the motivating aspect comes from making the process less monotonous, e.g. "*Without the timer, it would be monotonous*" (U9).

Another user suggested to "*make the timing intervals defined by each user, according to the training experience*" (U6), i.e. the more experienced the user is, the lower the timing intervals.

4.3 Controllability

Controllability implies being self-confident that the process is going well. The user should feel assured that the training is effective. In this perspective, qualitative data seems clear: "*Positioning, and coordination of the solution was easy to use*" (U1, U2, U3, U4, U6, U7, U9), the "*numbers helped*" (U4, U6, U7, U9). Even "*without stepping, the projection helps you see the sequence and what goes first (…) and I had no doubts thanks to the [visual cues] that were being displayed*" (U8). "*Without this I do not know if I could feel confident enough on how to walk with crutches*" (U8).

In this aspect, the qualitative data seems to suggest a negative point involved in this solution: the fact that the projection moves along with the user was sometimes referred as "*being a little confusing at the beginning*" (U5, U8).

[2] Throughout this section, U*i* refers to the user (i.e. the participant's ID in our evaluation).

4.4 Awareness

Being aware of their progress was also highlighted by the users in this experiment. The notion of progress is particularly important in behavior change support systems, as it motivates the user towards achieving a desired goal, even when the progress is slow.

In our case, the system was regarded almost as a game. In fact, some suggestions were given to "*gamify the system*", e.g. "*Maybe instead of showing different timings, [the system] could present different challenges: stairs, ramps*" (U4).

All these design considerations, empirically tested, are extremely useful for facilitating the design of persuasive systems, especially when those systems need to motivate people on how to proceed correctly with their training processes.

4.5 Limitations of the Study

As with all qualitative studies approaching novel systems for assistive technologies, this study has its own strengths and weaknesses.

In terms of limitations of the study, we highlight the following:

- The majority of participants had never walked with crutches before. This was not considered to be a major concern, since the target of the system is on helping users to learn how to walk with crutches, as specified in our RQ. However, it would be important to further assess the effect of ground space visual cues on users that have extensive crutch experience and/or major motor impairments.
- The study had a limited time duration. This means nothing can be claimed regarding the study's efficacy on the long term. To address this weakness, we are preparing a longitudinal study involving a representative sample of users.
- No study or assessment was performed regarding other types of gait training.

5 Conclusions and Future Work

Crutch walking is very different from gait rehabilitation in the sense there are no degrees of freedom. For instance, balance is limited, and the amount of applied strength is fine-tuned throughout the rehabilitation process itself. The main advantages of Augmented Crutches are portability and a reduced need for human intervention during gait training processes. However, Augmented Crutches also brings an important element of persuasiveness to a physical rehabilitation process that can be painful and can even lead to significant losses of self-confidence and self-awareness. Van Delden reports patients complaining about over stimulation of reflective light due to the led floor they used [8]. Our approach does not suffer from this effect. Subtle solutions are needed for achieving usable behavior change support systems.

By digitally augmenting the physical space around the user, our system helps people to learn how to walk using crutches with increased levels of self-confidence and motivation. Additionally, our work identifies timing, controllability and awareness as the key design dimensions for the successful creation of persuasive experiences for learning how to walk with crutches.

Future work, as suggested by some of the participants in the study, could include the development of an audio-enhanced version for the blind (suggested by U2), but should be essentially dedicated to improving the persuasive elements of the system. It should also focus on improvements to the technical design of the system in order to allow more detailed real-time adaptation to the users' gait speed and consideration regarding predictable achievement of the users' desired proficiency when using crutches.

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