Digitally Augmenting the Physical Ground Space with Timed Visual Cues for Crutch-Assisted Walking

Beatriz Peres
M-ITI, University of Madeira
Funchal, Portugal
beatriz.peres@m-iti.org

Pedro F. Campos
ITI/Larsys, University of Madeira
Funchal, Portugal
pcampos@uma.pt

Aida Azadegan
Intelligent Systems Research Laboratory,
University of Reading
Reading, UK
aida.azadegan@gmail.com

ABSTRACT

This late-breaking work presents initial results regarding a novel mobile-projection system, aimed at helping people to learn how to walk with crutches. The existing projection-based solutions for gait training disorders are based on walking over a fixed surface (usually a treadmill). In contrast, our solution projects visual cues (footprints and crutch icons) directly into the floor, augmenting the physical space surrounding the crutches, in a portable way. Walking with crutches is a learning skill that requires continuous repetition and constant attention to detail to make sure they are being used correctly, avoiding negative consequences, such as falls or injuries. We conducted expert consultation sessions, and we identified the main issues that patients face when walking with crutches. This

Permission to make digital or hard copies of part or all of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for third-party components of this work must be honored. For all other uses, contact the owner/author(s).
CHI'19 Extended Abstracts, May 4–9, 2019, Glasgow, Scotland Uk
© 2019 Copyright held by the owner/author(s).
ACM ISBN 978-1-4503-5971-9/19/05.
https://doi.org/10.1145/3290607.3312891

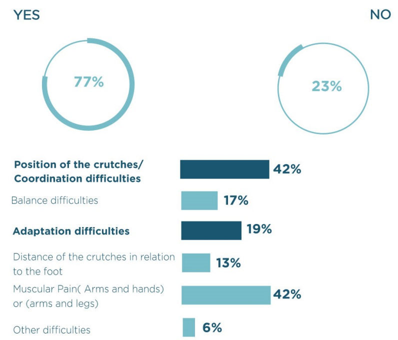

Figure 1: User research included a survey on crutch users (N=118). 77% reported significant difficulties when learning to walk with crutches, 23% reported not experiencing major difficulties. Among many other responses, it was clear that the major challenge was learning a proper positioning and coordination of the crutches. This research was triangulated with expert interviews who corroborated the results. Essentially, there is no digital solution that can properly teach how to position and coordinate the crutches. This inspired our approach and drove the design of Augmented Crutches.

informed the design of Augmented Crutches. We performed a qualitative evaluation and conclude with design implications: the importance of timing, self-assurance and awareness.

CCS CONCEPTS

• **Human-centered computing → HCI theory, concepts and models**;

KEYWORDS

Rehabilitation; Assisted Walking; Augmented Experiences; User Experience; Interaction Design; Augmented Reality.

INTRODUCTION

The number of people facing with the need to learn how to properly walk using the help of assistive devices is increasingly rising [3]. People with injuries, or with any sort of mobility problem, typically use mobility aids such as crutches, walkers or canes in order to be able to walk more independently and recover correctly. 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].

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 [3]. However, the use of this mobility aid can be associated to some negative consequences related to its incorrect use. Walking with crutches requires a deep understanding of a specific 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.

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 [1].

In this context, we present Augmented Crutches, a novel system aimed at helping people to walk with crutches in a portable, lightweight manner. Working in close collaboration with therapists, we identify the main issues that patients face when walking with crutches and used that information to guide the design process.

Figure 2: A user walking with Augmented Crutches.

Augmented Crutches studies human behavior aspects in these situations and augments the space around the user with digital indications where well-timed visual cues are the most important factor. This removes 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.

INTERACTIVE SYSTEMS FOR GAIT TRAINING AND WALKING REHABILITATION

We briefly review the current projection-based interactive approaches for gait training and rehabilitation, as so many have been proposed by researchers working towards different health interventions. In the case of walking with crutches, computers can help users perform better when they use these assistive devices, by showing them how they are performing, in a reflective-based manner. One approach is to visually project what the user is doing and receive guidance about what to do better and which aspects should be improved. For instance, Tsuda et al. 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) [7]. In our system, we also decided to include textual cues for the user to know how to walk with crutches and to persuade the user towards changing his behavior.

Visual cues are also popular, as they are a signal of something or a reminder of something [2]. They aim at being self-explanatory and pre-attentive. Visual elements were used to improve the walking skills of Parkinson disease patients [8] [5]. LightGuide [6] 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 [6].

Slekhavat et al. [4] 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.

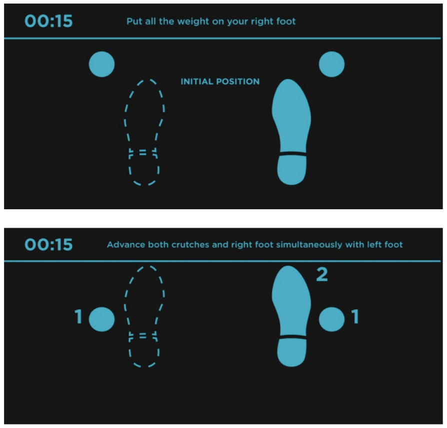

Figure 3: A sequence of gait training using the Augmented Crutches mobile projection system.

AUGMENTED CRUTCHES

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 crutch 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 2 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.

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

Personalization. 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 allowing to set the system accordingly. Through the user's answers about her or 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, among 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 3 illustrates a particular gait training sequence (in this case, for three-point gait).

Main Design Implications
When augmenting the user's ground space with a digital projection system of this type, three main factors revealed critical for the successful learning process:
Timing: Visual cues for teaching crutch-walking are the most critical design factor, since they help the user improve their locomotion at the correct rhythm or pace. Properly-timed visual cues need calibration, and we used the physiotherapist's experience to achieve that. A digital system should also adapt itself to the learning process of each user, which can vary over time.
Self-assurance: Self-assurance means being self-confident that the process is going well. The user should feel assured that the training is effective. Self-assurance is a critical design factor, especially when injured users are still at an incipient stage of learning, as they can easily lose all their self-confidence if an accident happens.
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.

Sidebar 1: Main Design Factors in Digitally Augmenting the User's Ground Space for Crutch-Assisted Walking.

EVALUATION AND DESIGN IMPLICATIONS

We conducted a qualitative evaluation in order to extract design implications that other interaction designers can consider when addressing this problem or similar approaches to digitally improving ambulatory rehabilitation experiences. 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. 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 use with the system and follow the visual cues (essentially the footprint and the crutch icon as exemplified in Figure 3). The first sequence of visual cues was shown for 15 seconds 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 took notes.

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) self-assurance, and (iii) awareness.

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). 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.

Self-assurance means 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).

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 useful for facilitating the design of assistive systems, especially when those systems need to motivate people on how to proceed correctly with their training processes.

ACKNOWLEDGMENTS

We thank all the volunteers and therapists for sparing their time and helping us design an effective solution. This project was partially funded by the FCT UID/EEA/50009/2019, by the Regional Project M1420-01-0145-FEDER-000002, and by the SUAVE project M1420-01-0247-FEDER-000019.

REFERENCES

[1] Clément Carpentier, Josep Font-Llagunes, and József Kövecses. 2010. Dynamics and Energetics of Impacts in Crutch Walking. *Journal of applied biomechanics* 26 (11 2010), 473–483. https://doi.org/10.1123/jab.26.4.473

[2] Frederica Gonçalves, Pedro Campos, Julian Hanna, and Simone Ashby. 2015. You'Re the Voice: Evaluating User Interfaces for Encouraging Underserved Youths to Express Themselves Through Creative Writing. In *Proceedings of the 2015 ACM SIGCHI Conference on Creativity and Cognition*. ACM, New York, NY, USA, 63–72. https://doi.org/10.1145/2757226.2757236

[3] Sheng Li, Charles W. Armstrong, and Daniel Cipriani. 2001. Three-point gait crutch walking: Variability in ground reaction force during weight bearing. *Archives of Physical Medicine and Rehabilitation* 82, 1 (2019/01/05 2001), 86–92. https://doi.org/10.1053/apmr.2001.16347

[4] Y. A. Sekhavat and M. S. Namani. 2018. Projection-Based AR: Effective Visual Feedback in Gait Rehabilitation. *IEEE Transactions on Human-Machine Systems* 48, 6 (Dec 2018), 626–636. https://doi.org/10.1109/THMS.2018.2860579

[5] Ben Sidaway, Jennifer Anderson, Garth Danielson, Lucas Martin, and Garth Smith. 2006. Effects of Long-Term Gait Training Using Visual Cues in an Individual With Parkinson Disease. *Physical Therapy* 86, 2 (2006), 186–194. https://doi.org/10.1093/ptj/86.2.186

[6] Rajinder Sodhi, Hrvoje Benko, and Andrew Wilson. 2012. LightGuide: Projected visualizations for hand movement guidance. *Conference on Human Factors in Computing Systems - Proceedings* (05 2012). https://doi.org/10.1145/2207676.2207702

[7] Naoaki Tsuda, Susumu Tarao, Yoshihiko Nomura, and Norihiko Kato. 2018. Attending and Observing Robot for Crutch Users. In *Companion of the 2018 ACM/IEEE International Conference on Human-Robot Interaction (HRI '18)*. ACM, New York, NY, USA, 259–260. https://doi.org/10.1145/3173386.3176968

[8] R. Vitório, E. Lirani-Silva, F. Pieruccini-Faria, R. Moraes, L.T.B. Gobbi, and Q.J. Almeida. 2014. Visual cues and gait improvement in Parkinson's disease: Which piece of information is really important? *Neuroscience* 277 (2014), 273 – 280. https://doi.org/10.1016/j.neuroscience.2014.07.024