

Augmented Crutches

Digitally augmenting the physical ground space
with timed visual cues for crutch-assisted walking

MASTER DISSERTATION

Beatriz Rodrigues Jardim Rino Peres

MASTER IN INTERACTIVE MEDIA DESIGN



UNIVERSIDADE da MADEIRA

A Nossa Universidade

www.uma.pt

July | 2019

Augmented Crutches

Digitally augmenting the physical ground space
with timed visual cues for crutch-assisted walking

MASTER DISSERTATION

Beatriz Rodrigues Jardim Rino Peres

MASTER IN INTERACTIVE MEDIA DESIGN

ORIENTATION

Pedro Filipe Pereira Campos



Augmented Crutches: Digitally augmenting the physical ground space with timed visual cues for crutch-assisted walking

Beatriz Rodrigues Jardim Rino Peres

Constituição do júri de provas públicas:

Eduardo Leopoldo Fermé, (Professor Associado com Agregação da Universidade da Madeira), Presidente

Pedro Filipe Pereira Campos, (Professor Associado com Agregação da Universidade da Madeira), Vogal

Diogo Nuno Crespo Ribeiro Cabral, (Professor Auxiliar da Universidade da Madeira), Vogal

Julho de 2019

Acknowledgements

First of all, I would like to thank my family, especially my parents for all the support since the beginning of this adventure. Without them, it would not be possible to achieve this important milestone. Also, to my close friends for all the motivation during this journey. However, I have to demonstrate my special gratitude to my supervisor, Prof. Dr. Pedro Campos. It would be impossible to complete this work without his belief on this project, his continuous support and motivation. His advice and guidance were essential to achieve the goals.

I would also thank the professionals from “Reabilitesse”: a special thanks to the physiotherapists Marisol Canada who kindly worked with us in every phase of the research as well as Catarina Castro. For this reason, thank you very much for all the help and patience during all this journey.

I would also thank to all the participants that participate on the earlier phase of the research in the problem of walking with crutches as well as the ones in the user tests of Augmented Crutches.

Finally, I would like to thank, as well, the financial support granted by the projects FCT UID/EEA/50009/2019, M1420-01-0145-FEDER-000002, and M1420-01-0247-FEDER-000019.

Resumo

Tecnologias persuasivas para reabilitação física têm sido propostas em várias intervenções de saúde diferentes, como a reabilitação da marcha pós AVC. Propomos um novo sistema de persuasão, chamado Augmented Crutches, com o objetivo de ajudar as pessoas a aprender a andar com canadianas. Pessoas com lesões, ou com qualquer tipo de problema de mobilidade, geralmente usam dispositivos auxiliares, como canadianas, andarilho ou bengalas, para poderem andar de forma mais independente. No entanto, caminhar com canadianas é uma habilidade que necessita de repetição contínua e atenção constante aos detalhes para que o utilizador possa andar corretamente com elas sem sofrer consequências negativas, como quedas ou lesões. Em colaboração com fisioterapeutas, identificamos os principais problemas que os pacientes enfrentam quando andam com canadianas. Estes variam de pessoa para pessoa, mas os desafios mais comuns e mais difíceis são a *posição* e *coordenação* das canadianas. Augmented Crutches estuda os aspetos do comportamento humano nessas situações e aumenta o espaço em torno do utilizador com elementos visuais digitais, onde o *timing* é o fator mais importante, sem a necessidade de um fisioterapeuta constantemente fornecendo ajuda manual. Isto é feito através de um mini-projetor ligado a um smartphone, usado de forma leve e portátil. O sistema ajuda as pessoas a aprender a andar usando canadianas com maior autoconfiança e motivação. Além disso, o nosso trabalho identifica o tempo, a controlabilidade e a consciencialização como as principais dimensões do design para a criação bem-sucedida de experiências persuasivas e interativas para aprender a andar com canadianas.

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 learn how 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.

Palavras Chave

Keywords

Palavras Chave

Canadianas

Reabilitação

Sistema de treino da marcha

Realidade Aumentada

Sistema de projeção

Mudança comportamental

Keywords

Crutches

Rehabilitation

Gait training

Augmented Reality

Projection-based Systems

Behavior change

Contents

1. Introduction	19
1.1 Motivation	19
1.2 Research Statement	21
1.3 Contributions	22
1.4 Publications	23
1.5 Dissertation Outline	23
2. Related Work	25
2.1 Walking with crutches	25
2.2 Weightbearing	28
2.3 Persuasive technologies for rehabilitation	29
2.4 Projection-based approaches	31
2.5 Cueing in rehabilitation	32
2.6 Related work overview	34
2.7 Summary	34
3. Design Space	36
3.1 Approach	36
3.2 Difficulties of walking with crutches	38
3.3 Summary	41
4. Implementation	42
4.1 Application	42
4.2 Architecture	43
4.3 Process	45
4.3.1 Answers to the questionnaire	45
4.3.2 Instructions: Adjust height	48

4.3.3 Instructions: Visual cues	49
4.3.4 Connect to projector.....	51
4.3.5 Gait training: Non-weight injured leg	52
4.3.6 Gait training: Some-weight injured leg.....	52
4.3.7 Gait training: Full weight injured leg.....	53
4.3.8 Gait training: Visual cues	54
4.3.9 Gait training: Textual cues	54
4.3.10 Gait training: Timing	55
4.3.11 Gait training: Feedback.....	55
4.4 Tools	56
4.4.1 Mockups of application	56
4.4.2 Software: Android Studio	57
4.4.3 Projection Device.....	58
4.4.4 Projection	58
4.5 Environment Setup.....	59
4.6 Summary	59
5. Evaluation	61
5.1 Methodology	61
5.2 Performance task	63
5.3 Participants.....	63
5.4 Results and Discussion	64
5.4.1 Qualitative Results.....	64
5.4.2 Timing	66
5.4.3 Controllability	68
5.4.4 Awareness	68
5.4.5 Limitations of the Study	68
5.5 Validation with Physical Therapist	69
5.6 Summary	71

6.Conclusion and Future Work.....	72
7.References	75
Appendix A.....	81
A.1 Questionnaire to Physical Therapists.....	81
A.2 Answers from the questionnaire	82
Appendix B.....	84
B.1 Questionnaire to Users that walk with crutches.....	84
B.2 Answers from the questionnaire	86
Appendix C.....	89
C.1 Questionnaire to Participants of Augmented Crutches	89
C.2 Answers from the questionnaire.....	91

List of Figures

Fig. 1. Forearm Crutches.....	26
Fig. 2. Three-point gait.....	26
Fig. 3. Four-point gait.....	27
Fig. 4. Single crutch gait.....	27
Fig. 5. Some answers of how users know how to walk with crutches	40
Fig. 6. Difficulties in walking with crutches	41
Fig. 7. What is the injured side?	46
Fig. 8. Can you put any weight?.....	46
Fig. 9. If yes, How much weight?	46
Fig. 10. Forearm Crutch	47
Fig. 11. Auxiliary Crutch	47
Fig. 12. Platform Crutch	48
Fig. 13. Adjust the height of the crutch	49
Fig. 14. Visual cue of crutches	50
Fig. 15. Visual cue of foot	50
Fig. 16. Visual cue of foot without any weight	50
Fig. 17. Connect the phone with the projector (App)	51
Fig. 18. Gait training of non-weight injured leg (example of left injured leg).....	52
Fig. 19. Gait training of some-weight injured leg(example of left injured leg)	53
Fig. 20. Gait training of some-weight injured leg(example of left injured leg)	53
Fig. 21. Gait training of all-weight injured leg(example of left injured leg)	54
Fig. 22. Visual cue (an exemple gait training non-weight left foot)	54
Fig. 23. Textual cue (an exemple gait training non-weight left foot)	55

Fig. 24. Timing (an example)	55
Fig. 25. Feedback	56
Fig. 26. Architecture	44
Fig. 27. Android Mockup in Marvelapp	57
Fig. 28. IOS Mockup in Marvelapp	57
Fig. 29. Projection Device	58
Fig. 30. Physical pockets for the system.....	59
Fig. 31. Participant testing (example)	64
Fig. 32. Augmented Crutches' motivating visual cue (an example).	65
Fig. 33. Use forearm crutch. (an example).....	66
Fig. 34. Augmented Crutches' changing timing (an example).....	67
Fig. 35. Age and gender of participants.....	86
Fig. 36. Country of participants	86
Fig. 37 Answers of participants about how they know how to walk with crutches....	87
Fig. 38. Answers of participants about how they know how to walk with crutches...	87
Fig. 39. Difficulties on walking with crutches	88
Fig. 40. Type of difficulties.....	88

List of Tables

Table 1. Relationship between design goals and visual cues. 37

Table 2. Differences between Augmented Crutches and VR solutions. 37

Table 3. Augmented Crutches evaluation stage..... 62

Table 4. Participants’ chacteristics..... 64

Introduction

1.1 Motivation

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 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].

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 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 not knowing if they are walking correct or not. Moreover, self-confidence can quickly be replaced with anxiety, especially if an accident or injury occurs [19].

The digital projection of visual cues is a technique used to place digital content about the gait and proper way to walk, giving the user a different perception about how he/she should walk.

Projection of visual cues could be a possible solution to overpass the lack of clear information and feedback when the Physical Therapist is not present. It holds a great potential in helping people to walk with crutches and there are already some studies (tools) available about walking rehabilitation to help the development process. [3,30].

If combined with a carefully designed application form of information about the patient, the projection of visual cues can be a great use in the rehabilitation process. The whole idea is to give more information to a person so that he/she can more easily execute the walking process with crutches. This information is usually given by a physical therapist. However, for non-taught and unsupervised exercises different approaches must be

followed on the type of information given to the user, making sure the user is walking correctly with crutches. A possible approach is to take advantage of projected visual cues of footprints and crutch icons that facilitates the way the user learns how to walk correctly with crutches.

1.2 Research Statement

In this work, we present Augmented Crutches, a novel system that help 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.

Augmented crutches aim to provide the means for users that had an injury for short or long term and need to walk with crutches to replicate the way of walking with crutches and guide the user during the walking training without supervision. During the rehabilitation process and taking into account that may change during rehabilitation our approach contributes to the correct performance of walking with crutches offering a form. Since the walking training process relies on repetition of the exercise of walking our approach builds a proper guidance, the patients can execute the gait training for themselves without supervision.

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.*

With this dissertation, we intend to study human behavior aspects in these situations and augment the ground 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.

We can then highlight the research statement of this dissertation as follows:

“Augmented Crutches : A novel mobile-projection system, aimed at helping people to learn how to walk with crutches correctly”

1.3 Contributions

With the development of our Augmented Crutches prototype, our work provides the following contributions:

- **A solution for unsupervised training on walking with crutches**

This solution augments the ground space around the user with digital indications where timing is the most important factor, without the need for a constant therapist providing manual help.

- **Portable content projection on a floor**

People need to train their crutch-walking alone, ideally *anytime, anywhere*. The goal is not to replace the physical therapist, but rather to have a cost-effective, portable solution that addresses the real needs of people who unfortunately need to learn how to walk with crutches.

- **New visual design**

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. Visual cues (footprints and crutch icons) directly into the floor, augmenting the physical space surrounding the crutches.

- **Improved Motivation**

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.

1.4 Publications

The work developed in this dissertation led to several publications blind-reviewed and evaluated by international panels of experts, being accepted in top scientific conferences. The publications are listed below.

1. Beatriz Peres, Pedro F. Campos, Aida Azadegan, *A Persuasive Approach in Using Visual Cues to Facilitate Mobility Using Forearm Crutches*. BCSS@PERSUASIVE 2019. [43].
2. Beatriz Peres, Pedro F. Campos, Aida Azadegan , *Digitally Augmenting the Physical Ground Space with Timed Visual Cues for Crutch-Assisted Walking*. CHI Extended Abstracts 2019. [44].
3. Beatriz Peres, Pedro F. Campos, Aida Azadegan , *A Digitally-Augmented Ground Space with Timed Visual Cues for Facilitating Forearm Crutches' Mobility*, INTERACT(1) 2019:184-201. [45].

1.5 Dissertation Outline

This document is structured with the help of five main sections to better understand the development of our application; Augmented crutches. Each section is divided into different sub-sections that help with the organization of the document. Section two describes the related work; section three describes our approach to the problem; section four describe the prototype and implementation of the created prototype. Section five contains the evaluation of the prototype. Finally, section six contains the conclusions of our work and some ideas to be implemented in the future.

Related Work

2.1 Walking with crutches

There are different types of crutches for different situations. Our work focused on forearm crutches, illustrated in Figure 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].

Proper positioning and coordination are important so that the whole weight does not fall on top of the injured side, aggravating the injury. As an example, consider someone who mistakes the position of the crutches and first places the “good” foot down, leaving all the load on the injured side, this would be enough to worsen the injury, and most importantly could leave the patient less motivated.

There is no metric defining the correct distance between crutch and foot. Physiotherapists use their experience and expertise on a case by case analysis, trying that the patient does not lose balance, or place the foot too far to the front. Physiotherapists also pay special attention to the sequence of movements, but this is all performed empirically and without any formal metric. The crutch must stay in the same direction as the foot not being in the front of the foot or in the end of the foot. The most important thing is the correctness of the position and sequence of movements.



Fig. 1. Forearm Crutches.

There are several different methods for walking with crutches. These depend 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.

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 Figure 2: both crutches move forward then the good leg moves forward, the affected leg goes simultaneously with the good leg. This type of gait is employed when the patient has no strength in the injured leg.

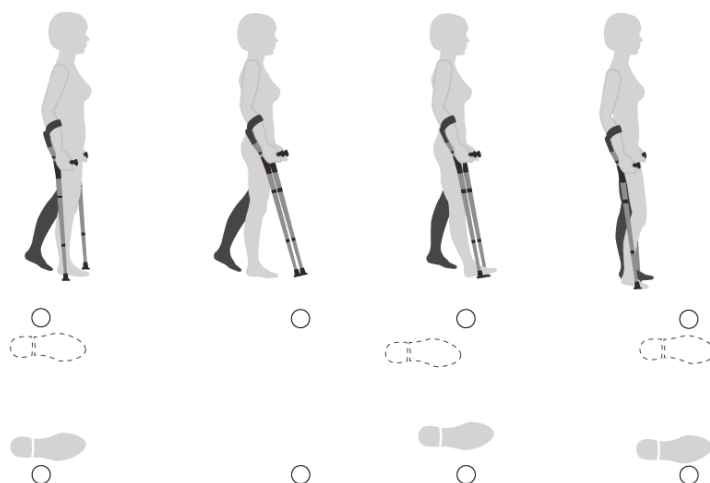


Fig. 2. Three-point gait.

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 (Figure 3) is the following: right crutch first and 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.

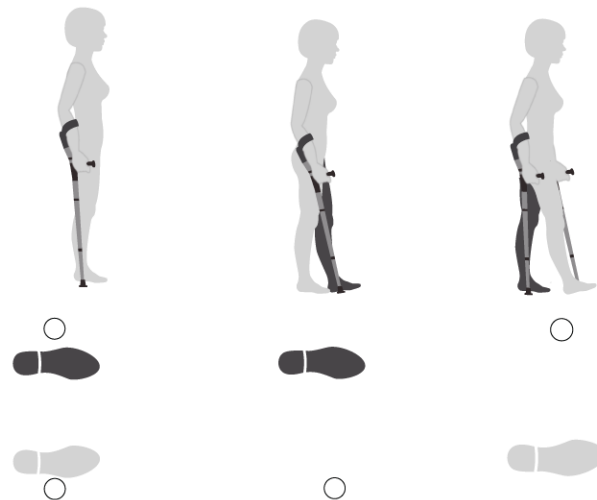


Fig. 3. Four-point gait.

Finally, single crutch gait (Figure 4). When the weight bearing in the injured leg is 100%. The crutch 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.

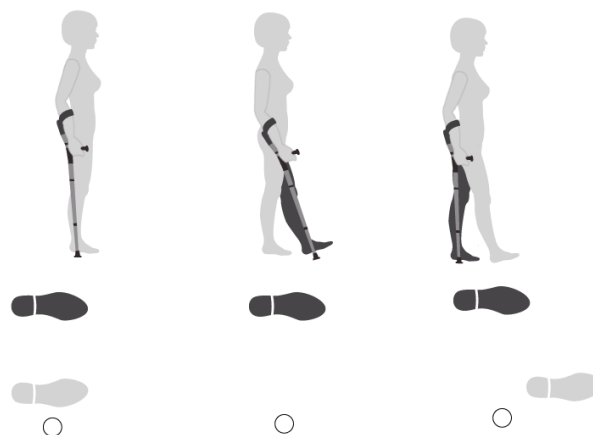


Fig. 4. Single crutch gait.

2.2 Weightbearing

The weight bearing in orthopedics is the amount of weight that the patient puts on the leg that have the surgery, this is also considered as a percentage of the body weight. Some studies use ground reactive force to analyze the percentage of body weight during different weight bearing conditions [1, 17, 18]. Li et al. [1] investigated ground reactive force during partial weight bearing and found that are large individual variations in ground reactive force because patients cannot control the load on the involved side as prescribed.

The weight bearing through the hands and arms while walking with crutches is used to compensate the weightbearing in the lower extremities. Clinically, patients who use a forearm crutch report having pain in their hands or arms (or both), during walking with crutches.

Incorrect weight bearing has been shown to result in an extended recovery period or even cause future damage to the limb.

Some studies show that the patients receive training before leaving the hospital from clinician [10]. As a patient, the perception of the amount of weight in their lower limb is usually prone to some errors.

However, the ability of the patient to remember how to use correctly crutches is limited, because when the patient returns to his home environment, and with the absence of the therapist, the patient easily forgets how to use crutches correctly. The many routine distractions of the daily life can influence the ability of the patients to comply with the recommended type of crutch gait: the position of the crutch and the amount of weight bearing that was recommended by the therapist.

Related to the issue of remembering the correct weight-bearing during walking with crutches, some researchers conclude that it is fundamental to create measuring instruments in daily life that monitor or control the patient perform on the injured, the amount of weight.

Many devices have been developed in the past to monitor the weight-bearing which is exerted through the patients' shoes. Gonzalez et al. [25] have recently developed a system for gait monitoring based on a wireless sensorized insole. However, although

sensorized insoles allow them to identify foot pathologies, they have to be adapted to each specific user (e.g. foot size) and require using shoes. Develop GCH system 2.0 [25] that presents a compact and read-to use device in order to perform gait outdoors and many patients can be walking with instrumented crutches at the same time. It's a device focused on accurately monitoring the force applied to the crutches during gait provide personalized feedback to both the patient and physiotherapist/researcher in order to improve gait training and evaluate the process of functional recovery. Merretti et al. [10] proposed a device that is designed for biofeedback in assistive healthcare. Forearm crutches augmented with low-cost wireless sensors for use both in hospital training and patient monitoring over the full recovery including its potential use in home environment the crutches monitor the force being applied through their axis, enabling on indicate and objective estimation of the weight bearing exerted through the affected limb to be obtained.

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 [2, 3]. However, we could not find any study or device related to crutch gait, i.e. the coordination between the footstep and the crutch, which exhibits changes throughout the rehabilitation process.

2.3 Persuasive technologies for rehabilitation

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 [18, 27]. For example, Luo et al. [29] developed a training environment that integrates augmented reality (AR) with assistive devices for post-stroke rehabilitation and training.

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.

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 (Aml) [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.

2.4 Projection-based approaches

The use of projection based for guiding users through task have been used in physical rehabilitation because they can bring benefits to guide the user by being able to focus the attention to the projection. In fact, these techniques have even been used in contexts such as enabling more playful interactions in the virtual reality continuum [42] 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.

2.5 Cueing in rehabilitation

Cueing is defined as using external temporal or spatial stimuli to facilitate the initiation and continuation of movement (gait) [31], 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 [32].

Auditory signals are a form of rhythmic cues which reportedly also improve gait. Cueing techniques such as musical beats [33, 34], metronomes [33], rhythmic sound [35] or verbal instructions [36] have been implemented to improve gait. Auditory cues have been demonstrated to increase speed gait [34].

Suteerawattanannon et.al. [36] 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 [37], adaptive glasses [38]. Recently, laser guided walking visual cue such as projection of visual cues [30], projection of lines [3], and laser-guided walking canes [40] have been used.

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

Some studies found that placing visual cues can effectively regulate stride length, improving gait and also that patients retained a positive carryover effect after the cues are removed [9, 11].

Both visual and auditory cues have been highly effective in improving gait walking in patients 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 than each one alone [36].

Suteerawattanannon et al. [36] show that both visual or auditory cues significantly improve gait performance but each one has a different impact. Gait speed was found to significantly increase with auditory cues and stride length was effectively influenced by the use of visual cues.

2.6 Related work overview

The use of projection approach might bring some visual improvement with visual cues. Based on the *Rehawalk* [6] there are reasons to be optimistic about this possibility. With *Rehawalk* [6], projection approach was applied only to a treadmill, but their results are good motivation to extend projection approach to the learning to walk with crutches and experiment with it but on a floor and not in a treadmill because of the movement of the treadmill. This technique has been normally used for walking rehabilitation and, to our knowledge, has not been explored in rehabilitation context when walking with crutches.

After analyzing examples of cues examples, it is possible to make some conclusions about their usefulness. Indeed, each of three type of cues observed, named visual, audio and haptic have shown to be for different purpose. 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 with current literature that refers e.g. its effectiveness in issues like Parkinson's disease gait training [30]. For this reason, the best option to guide a patient through movements seems to be by using visual guidance.

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 using visual working memory (VWM).

2.7 Summary

In this Chapter, we provided an overview of the state of the art regarding our work. Firstly, we describe how to walking with crutches . Secondly, we review the existing of Persuasive technologies for rehabilitation focused on helping patients in recovering with a less dependency on professional supervision. Thirdly, we described the state-of-the-art regarding the use of Projection-based approaches in a rehabilitation context we described some interesting works that, even though not aimed for walking with crutches, could be applied in this same context.

Fourthly, we provided some insight related to Cueing in rehabilitation and the different types of cues comparing different approaches describing some works that aim for rehabilitation however could be applied in this context of walking with crutches.

Finally, we make a features comparison between, what we considered, the main presented works and our approach. Following this chapter, we describe our proposed approach.

Design Space

This chapter describes a new approach to deal with the various Augmented Crutches implementation challenges, and identifies the critical resources required for a successful implementation. We present the design options for providing the visual information.

In this section, we describe our method, which involved designing the system with the help of experienced therapists, developing in an agile way [28], then evaluating it with a representative sample of target users, and finally discussing the clustered qualitative results.

3.1 Approach

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.

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.
---------------------	-------------------------	---

Table 1. Relationship between design goals and visual cues.

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 own personal experience as well as from the user research we performed. We are striving for portability and effectiveness.

	Augmented Crutches	VR Solutions
Special equipment	Require a special equipment that is the projector but is a equipment that is cheaper.	VR solution require a special equipment that is normally very expensive.
Portable	With the use of a projector the user is not limited to one space and can do the training where he wants (as long as light conditions allow it).	Some VR solutions only can be use in one place.
Confusion	Use the real space where the user can see what to do.	VR solution can cause some confusion in the rehabilitation.

Table 2. Differences between Augmented Crutches and VR solutions.

Interviews with therapists made by me (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. Augmented Crutches has ambitious goals, aiming further beyond the accomplishments achieved by Rehawalk. As described in the previous section, Rehawalk only focused on projecting information on treadmill, 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.

Our approach should guide users in to walk correctly with crutches showing the position of the foot and crutch. Augmented Crutches should follow a specific process, which will be explained in the section.

3.2 Difficulties of walking with crutches

People who walk with crutches feel difficulties on understanding how to walk with crutches. This was inferred from simple consultation to different specialized websites such as the American Academy of Orthopedic Surgeons (AAOS)¹ that provide advice on how to safely and efficiently walk with crutches, where the amount of information and the credibility are evident enough to conclude that people feel difficulties on walking with crutches.

The main challenge that we addressed was the learning of correct positioning and coordination of the crutches. Position and coordination (as main challenges) were

¹ See e.g. <https://orthoinfo.aaos.org/en/recovery/how-to-use-crutches-canes-and-walkers/>

identified through four different sources which we will clarify in the next version of the manuscript: (i) own personal experience as a user of crutches , (ii) extensive interviews which were made to experienced physical therapists, 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); (iii) interviews which were made to people that already experience to walk with crutches; and finally (iv) known literature, e.g. [1, 2]; This literature includes illustrated manuals of nursing practice as well, which document the problem in a very clear manner².

My own experience in walking with crutches is inline that the biggest difficult felt during such experience in walking with crutches is position and coordination. Felt a little lost when was at a home environment because she was alone and was not sure if she was walking correctly with crutches and nobody tells her how to walk with crutches in the beginning of rehabilitation.

In the interviews that were made by me with the physical therapists, they also mention that the biggest difficulty they observe is people feeling difficulties in the position and coordination of crutches this seems to be because *“they confuse a lot since they never know which one (crutch) goes first, mostly forget because of that and especially the people with more age gives up and they have to use other walk assistance”*.

The position and coordination is fundamental to walk correctly with crutches because, as the physiotherapists explained, *“in terms of position and coordination, it is critical to not put all the weight on the injured side”*.

During rehabilitation the position of crutches and the coordination between the crutch and foot change during the process of rehabilitation not being all the same. Generally, people during rehabilitation do three types of walking with crutches that also make some confuse to people, like the physical therapists said. The questionnaire and answers of the physical therapists are available in the Appendix A.

In the interview with the people who already use crutches expressed to agree that the biggest difficult that they feel when walking is position and coordination of the crutches,

² See e.g. *Illustrated Manual of Nursing Practice*, Springhouse Ed., 3rd ed, ISBN-10 1582550824

thereby having the same opinion as the physical therapists. The questionnaire and answers of these users are available in Appendix B.

This questionnaire was made to the target audience (people who already walk with crutches) via google forms that didn't know the answers given by the physical therapist so that they would not be influenced by their answers. We interviewed 118 participants (33 female, 85 male) , 30,28 years old from around the globe also to conclude if was global problem or not. All the participants already walk at least one time with crutches. Being taught on walking with crutches, 51% answers that were not taught on how to walk with crutches. 51% of participants said what they did to know how to walk with crutches . The most common answers were: "I didn't" (20%) , "Looked for the most comfortable way to walk for me"(15%) , "By watching others"(15%) , " I don't know" (12,5%) , " Trial and error" (10%) , " Intuition" (12,5%) which can be seen in Figure 5. With this we conclude that not everyone is taught to walk with crutches and that people feel a little bit lost because they don't have any information and do not know how to walk correctly with crutches.

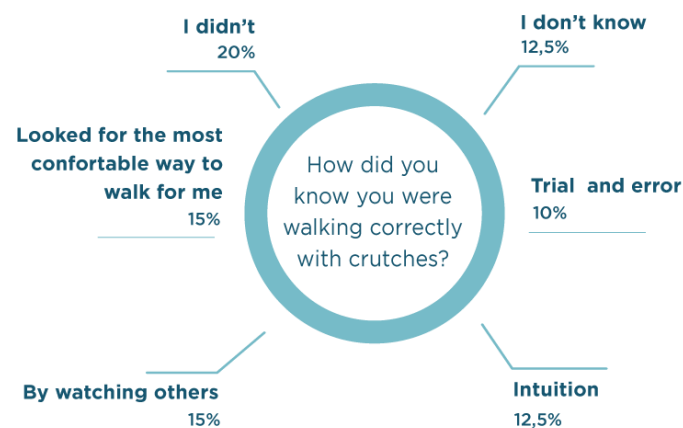


Fig. 5. Some answers of how users know how to walk with crutches

Finally, about difficulties felt on walking with crutches, 77% said that feel difficulties during walking with crutches. The difficulties identified were: Position and coordination (42%), Balance Difficulties (17%), Adaptation Difficulties (19%), Distance of the crutches in relation to the foot (13%), Muscular Pain (42%) and Other Difficulties (6%) which can be seen in Figure 6.

With this, we conclude that the biggest difficulty felt by the users is Position and coordination, being these users taught or not to walking with crutches, what we can conclude that the difficult observe by the physical therapist and the users are the same.

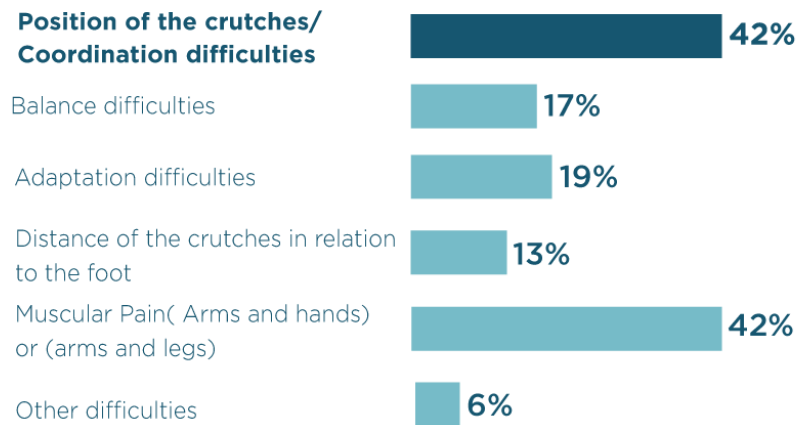


Fig. 6. Difficulties in walking with crutches

3.3 Summary

In this chapter we explained our approach for the presented problem. Firstly, we introduced design goals of Augmented Crutches. Secondly, we start describing the difficulty in walking with crutches that we addressed was the learning of correct positioning and coordination of the crutches. Position and coordination (as main challenges) were identified through different sources.

Implementation

4.1 Application

Android studio³ was the platform employed for building the mobile app. Ideally, each user would be able to create a personal account in order to save the data and the gait training sessions. However, this more robust system was not implemented because our focus was on the visual cues and the training process, rather than the full-scale system implementation, which can come at a later phase once the prototype is thoroughly evaluated.

Physiotherapists, among many other aspects, were helpful in the design of the selection choices for each gait training type. In order to program the proper timing of the cues' display, we had to add a timer so that each user can clearly see how much time is left as well as the duration of the gait training session. The timer is shown in-between sessions as well as before the start of each gait training session. Augmented Crutches prototype was built to walk correctly with crutches and complying with the solution requirements. The prototype had to rely on some already existing devices to implement all planned features, namely the android studio software for the application and a fabric for the belt and the pockets to put the projector and the mobile phone. Also, a portable projection device for the projection of gait training visual cues, connected to the mobile application.

After describing Augmented Crutches' testbed and architecture, as well as the employed devices, this chapter will present a description of the most important implementation details.

³ See <https://developer.android.com/studio/>

4.2 Architecture

The Augmented Crutches architecture, which can be seen in Figure 26, relies on some devices for both receiving and sending information for the user.

In terms of adapting gait training to the user rehabilitation, we have that information through an application aimed at providing the correct gait training. Sections 4.4. will explain more in detail what devices were used and what software we use and how we were able to provide the gait training correctly.

Given the information about correct gait training, the application needs to be connected to projector for the user according to the specific exercise have to execute by making usage of the light projector to project information on the floor.

Section 4.4.3 explains in detail how this projection was achieved.

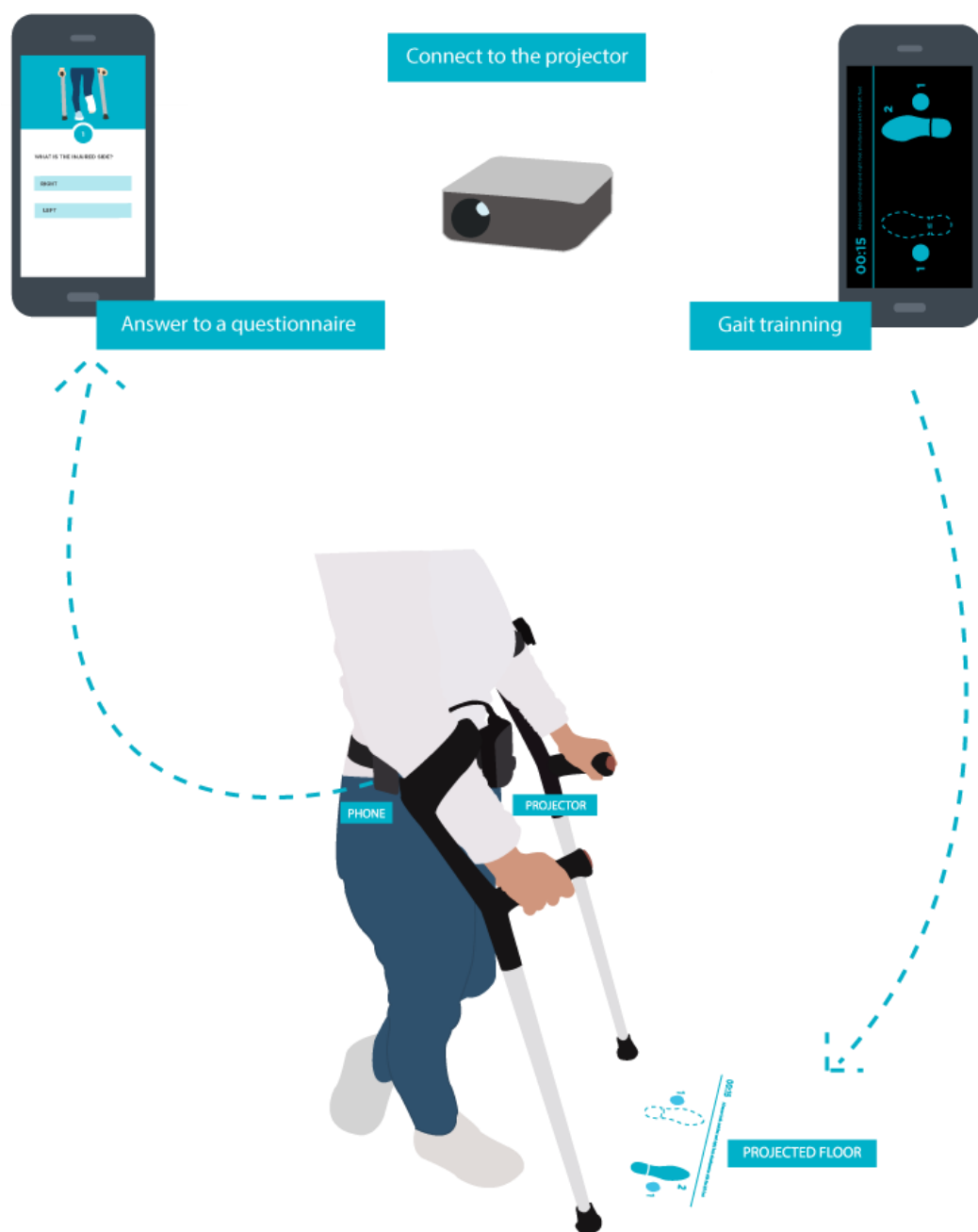


Fig. 26. Architecture


4.3 Process

The Augmented Crutches process can be divided into three main phases. The first one, **Answers to the questionnaire**, available in a mobile application about the physical condition of the user. Next we have **Connect to projector**, which focuses on connect the phone to the projector in order to after be able to performed the gait training that was generate according to the answers given in the questionnaire. Our final phase, **Gait training**, provides to the user the correct position of the foot and crutches for the user train the walk with crutches correctly. Each of these phases will be individually described in the following sections.

4.3.1 Answers to the questionnaire

There are different types of gait training with crutches. 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: "What is your injured side?", "Can you put any weight on the injured side?". To the question "Can you put any weight on the injured side?" is a question that if the user does not have any supervisor that tells him the amount of weight that can put or should put on the injured side, the user should use the level of pain in the injured side.




1

What is your injured side?

RIGHT

LEFT

Fig. 7. What is the injured side?




2

Can you put any weight on the injured side?

YES

NO

Fig. 8. Can you put any weight on the injured side?



3

How much weight?

SOME

ALL

Fig. 9. If yes, How much weight?

Before the answer of the questionnaire the users have some information about the types of crutches if the users want to know more information about crutches

considering that the aim of the project was to help person to walk with crutches without supervision and do not know the circumstances that the user is using crutches and that for any reason need to know this information.

The forearm crutch is the most common to be used in rehabilitation , because it can be used for any weight in the injured side, from just some weight up to total weight. The other two crutches are less common, the axillary crutch is mostly used when cannot put any weight on the injured side, the platform crutch is rare to be used and only for a specific type of user that has little strength in the hand due to conditions such as arthritis



Fig. 10. Forearm Crutch

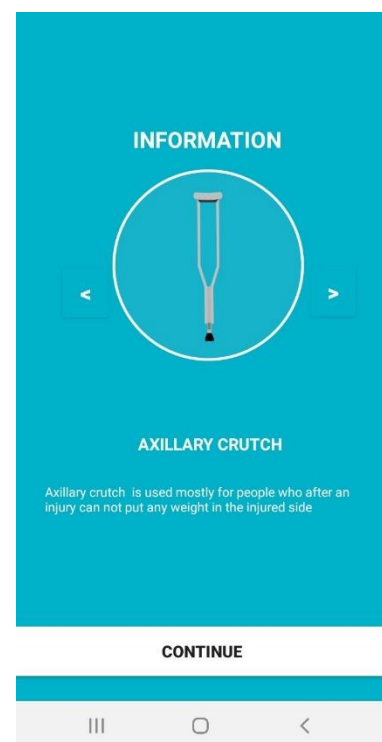


Fig. 11. Axillary Crutch

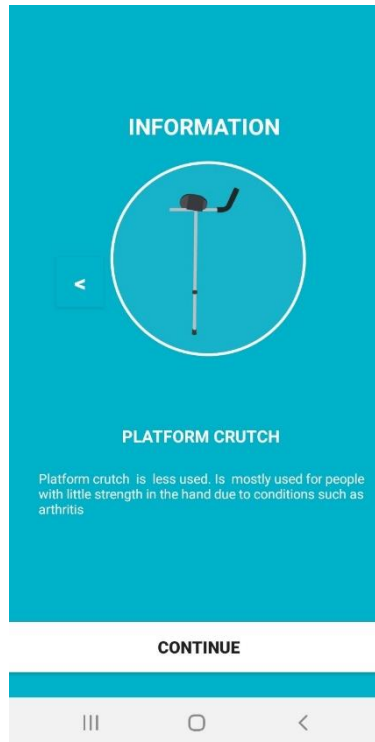


Fig. 12. Platform Crutch

4.3.2 Instructions: Adjust height

Adjust height of the crutches is an information that is provided to the user after the questionnaire. The height the crutch should be adjust to the height of the user. The cuff of the crutch should be 2-3 fingers below the elbow for the user walk correctly with crutches. Its fundamental that the user adjust the height according to his height because if is not correctly adjust can have postural problems.



Fig. 13. Adjust the height of the crutch

4.3.3 Instructions: Visual cues

The visual cues provide information about the position of the foot and the crutch, as well as the sequence of movements, for the users understand well the significant of each visual cue during the gait training to perform the gait training correctly before the gait training the user can learn the significant of each visual cue.

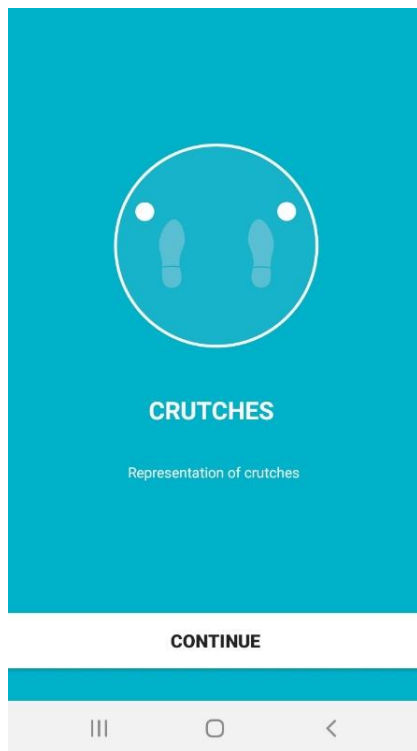


Fig. 14. Visual cue of crutches



Fig. 15. Visual cue of foot

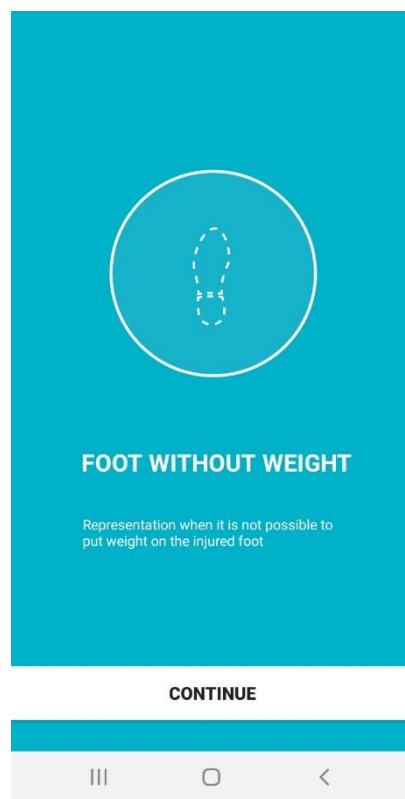


Fig. 16. Visual cue of foot without any weight

4.3.4 Connect to projector

There is a belt that contains a front pocket where a Philips PicoPix mini-projector is connected to the previous mobile app (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. In order to then to be able to perform the gait training.

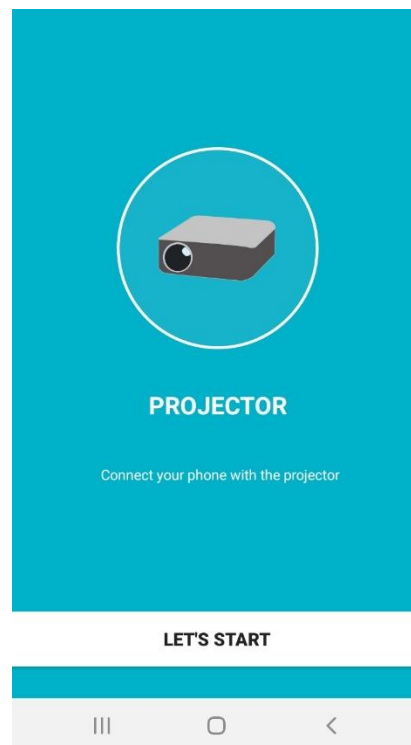


Fig. 17. Connect the phone with the projector (App)

As described in section 2.1 there are different types of gait training with crutches. Through close collaboration with physical therapists, we designed as a solution to address the main three different gait training types: three-point gait, four-point gait and single crutch gait.

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.

4.3.5 Gait training: Non-weight injured leg

The gait training type of three-point is the gait training design for someone that cannot put any weight on the injured foot. To do this gait training the user should advance both crutches and then good foot simultaneous with the injured foot. More detail in the figure below.

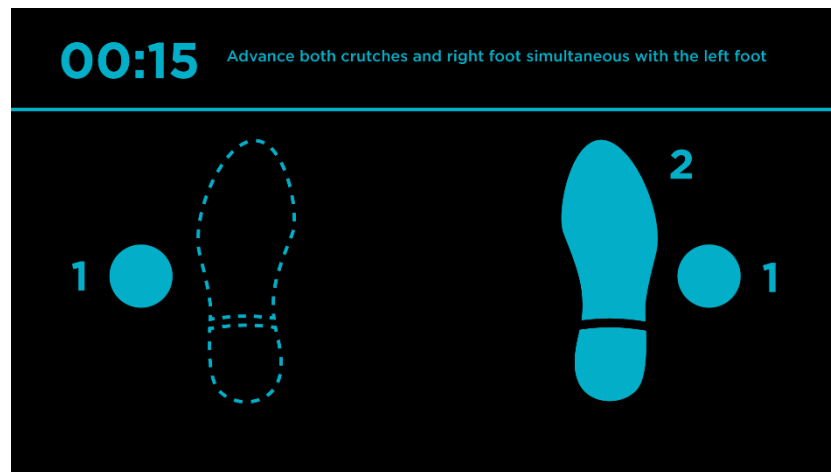


Fig. 18. Gait training of non-weight injured leg (example of left injured leg)

4.3.6 Gait training: Some-weight injured leg

The gait training type of four-point is the gait training design for someone that can already put some weight on the injured leg. To do this gait training the user should advance the crutch of the good side and injured leg, then crutch of the injured leg and good leg. More detail in the figure below.

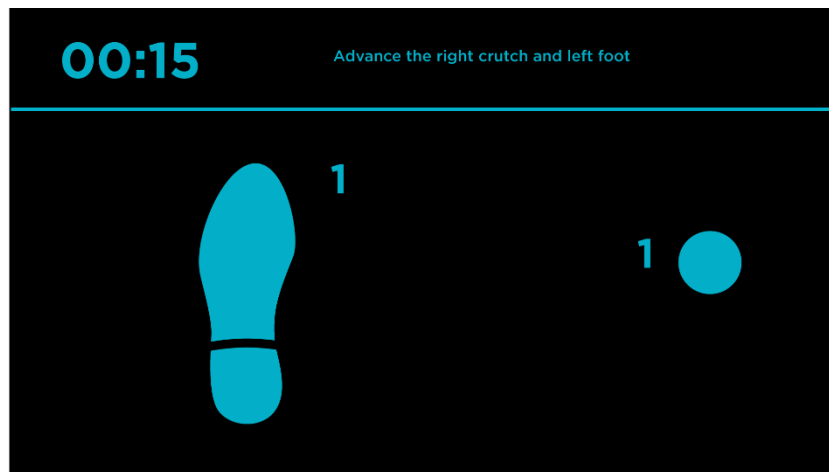


Fig. 19. Gait training of some-weight injured leg (example of left injured leg)

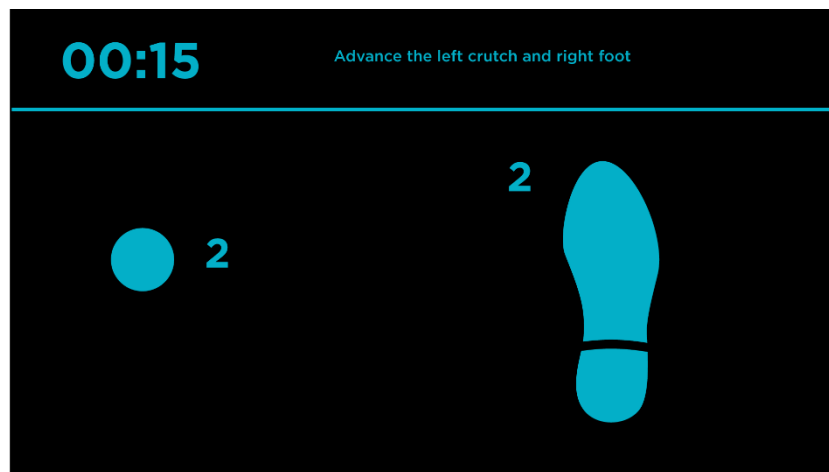


Fig. 20. Gait training of some-weight injured leg (example of left injured leg)

4.3.7 Gait training: Full weight injured leg

The gait training type of single crutch gait is the gait training design for someone that can already put all weight on the injured leg but still need some support. To do this gait training the user should only use one crutch and be on the opposite side of the injured leg. Advance the crutch and injured foot then good foot. More detail in the figure below.

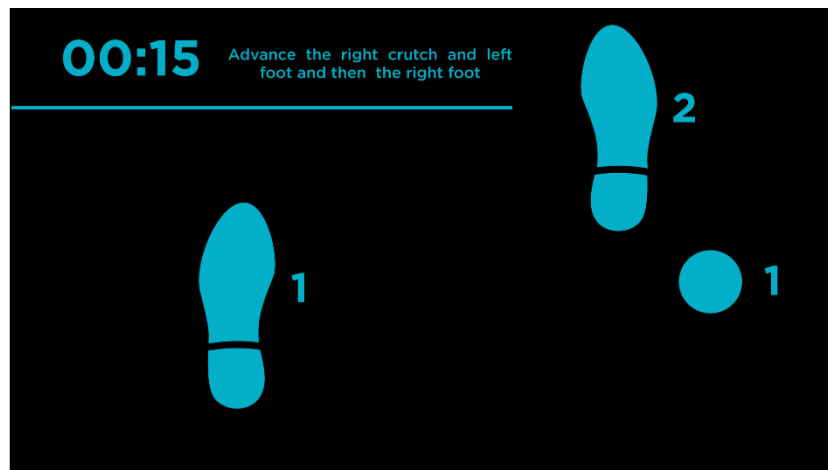


Fig. 21. Gait training of all-weight injured leg (example of left injured leg)

4.3.8 Gait training: 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.

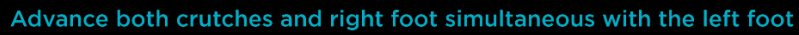
The choice of blue color is related to the inspiration in the symbol of physiotherapy where blue predominates.



Fig. 22. Visual cue (an example gait training non-weight left foot)

4.3.9 Gait training: Textual cues

The textual cues provide information about the sequence of the movements (crutch and feet) as a complement of the visual cues.



Advance both crutches and right foot simultaneous with the left foot

Fig. 23. Textual cue (an example gait training non-weight left foot)

4.3.10 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.



00:15

Fig. 24. Timing (an example)

4.3.11 Gait training: 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.

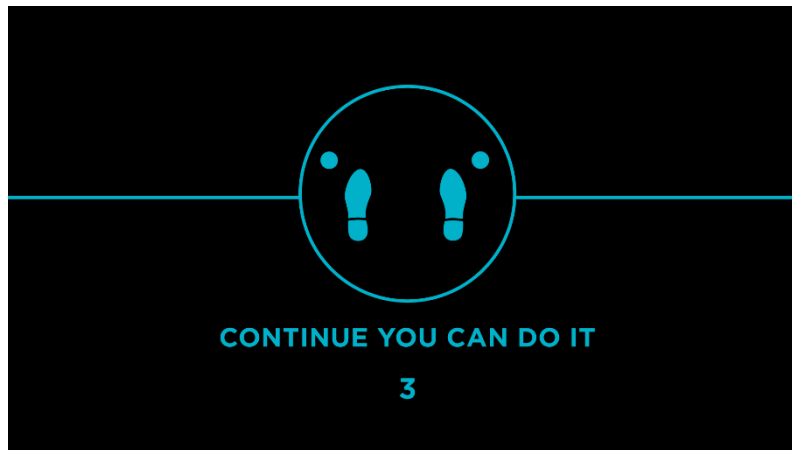


Fig. 25. Feedback

4.4 Tools

The Augmented Crutches implementation was aided with the usage of already existing tools.

Mockups in Marvelapp were employed for the first stage of the application to provide all the instructions for the gait training, also to decide the design of the application. Android studio was employed as a software to the application to provide the user the most “real” experience to then have the gait training correctly.

The usage of projector was to use the light of projector to project the information on the floor to facilitate the execution of the gait training correctly by the user.

4.4.1 Mockups of application

Providing effective gait training could be considered one of the foundations of this work. We chose to first to implement a android and iOS mockup of the application to provide to the user a easy and intuitive use of the app to have access to the correct gait training according to what the user is feeling in the injured leg to execute the gait training adapted to him.

As previously described in the section 4.2.1, our plan was to first apply a questionnaire about the injured side and the amount of weight that can put on the injured leg should be the most intuitive and easy to understand. To provide a better understand of the questionnaire to have the correct gait training we use more popular words to be easier

for the user. We also conclude the lack of some information that should be include in the application for the user doesn't have any doubt like:

- 1- Add information about the types of crutches
- 2- Instructions

Details about the application and the answer questionnaire is explained in the Section 4.2.1

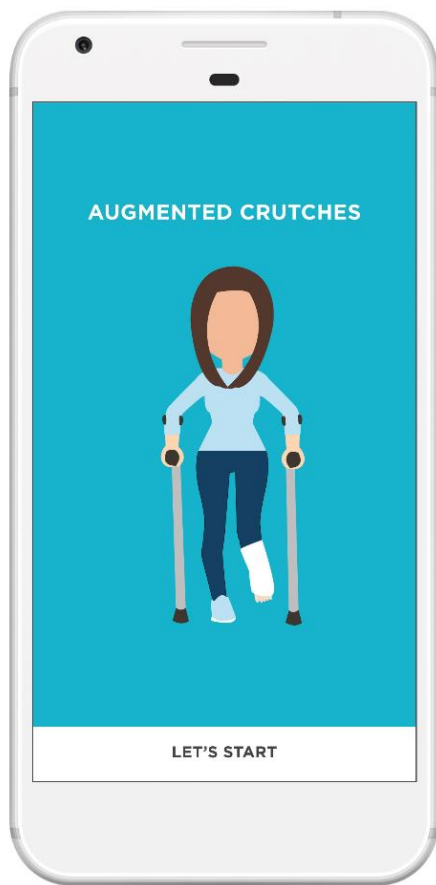


Fig. 27. Android Mockup in Marvelapp

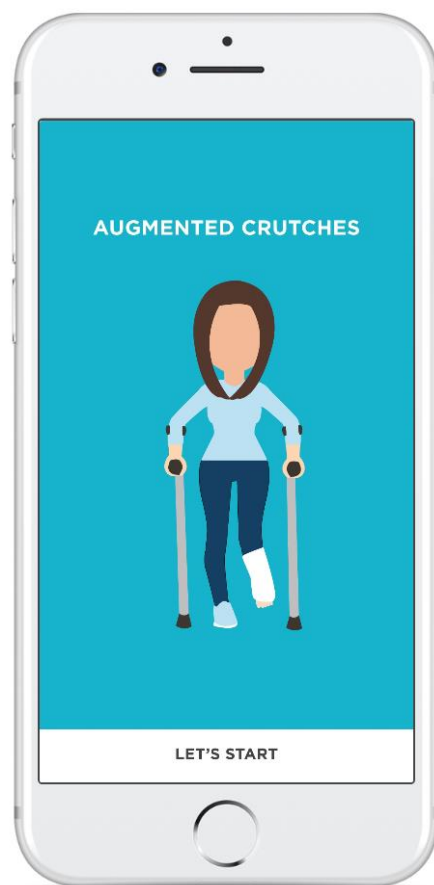


Fig. 28. iOS Mockup in Marvelapp

4.4.2 Software: Android Studio

We chose to implement our prototype with the Android Studio⁴. There already exist some videos on internet and tools that facilitate the development of the Android application. In addition, Android studio uses Java that is programming language is a

⁴ See <https://developer.android.com/studio/>

common language to create a android app and it and it already overs a wide range of solutions to create visual information.

4.4.3 Projection Device

To effectively provide the projection of the information with the little device could be considered one of the foundations of this work. We chose a Picopix to be a portable little device to the user easy execute the gait training not having a lot of weight to carry to be able to use this device on the waist to be then be able to the projection be direct to the floor being our goal in this implementation.



Fig. 29. Projection Device

4.4.4 Projection

Projection of visual information on the floor was one of the greatest challenges for our implementation. To accomplish it, we divided the implementation in small goals.

First, we need to create and understand how we are going to put the projector to be on the waist of the user to be comfortable, to not fall the projector during the training and to the information be direct to the floor.

Figure 30 shows the two physical pockets that are used to carry the mobile phone and projector. This is important to make sure the projector does not interfere with the walking process. There is an adjustable band in order to put the projector well adapted to each user's body.

It is important to note that there is no “correct” distance between projection and user, the only issue that matters is to make sure the user sees the visual cues to properly perform the gait training. As mentioned before, Augmented Crutches is meant to be used in the initial phase of crutch-walking training.

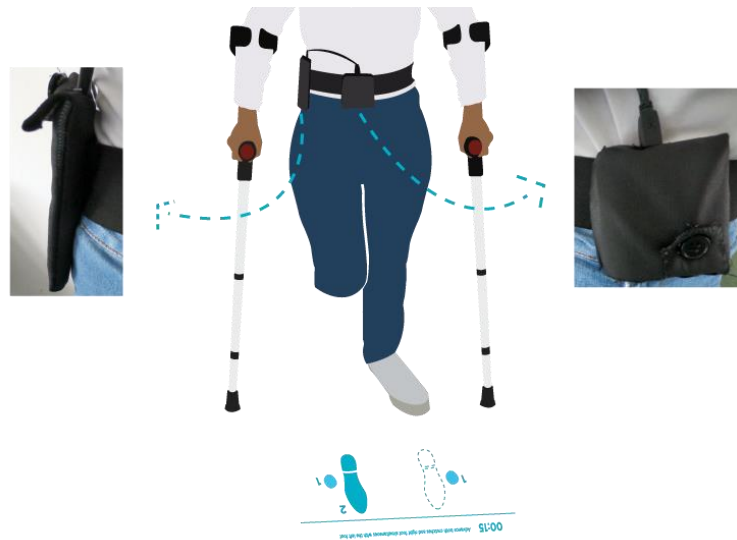


Fig. 30. Physical pockets for the system

4.5 Environment Setup

The floor should have very few textures so that the projection is clearly perceptible, and also so that the patient does not get distracted. Considering the small form factor of the projector, the luminosity is not high, therefore the system is meant for indoor use.

4.6 Summary

In this chapter we introduced the Augmented Crutches prototype and described its implementation.

Firstly, the architecture was presented, followed by the already existing devices that were used in our implementation. Firstly, we introduced the three main phases of what we consider to be Augmented Crutches's process.

Secondly, we start describing each phase, where present type of question that the user will have to have the gait training while explaining the instructions that the user will have before training the gait training

Thirdly, we explain which gait training that are in the application while we present our planned visual design to be used when guiding users through gait training. Finally, we describe how will each element of gait training is used in our approach

Secondly, we described the set of tools developed and devices used to build our Augmented Crutches prototype

In the following chapter, we describe the tasks and methodologies performed to evaluate our prototype and present our statistical analysis of the overall results.

Evaluation

Summary

To evaluate Augmented Crutches, we intended to observe how well a subject walk with crutches just by following the projection of visual cues. Since tests involve executing gait training, having the three-gait training each one according to the amount of weight in the injured leg were created for this evaluation. These exercises were simultaneously recorded both by video and by taking notes. This way, we guarantee the same gait training is being stored in video and taking notes during observation.

This chapter presents a detailed description of the experimental tests. It addresses the experimental methodology employed for testing our prototype with test subjects, the category of performed tests, the measurement metrics, and the characteristics of the collected sensor information. It also presents the experimental results and their critical analysis. All the results will be discussed in order to achieve a better understanding about our prototype functionality and performance. Finally, the chapter reports some of the most important critics elaborated by a professional physical therapist after using our system.

5.1 Methodology

This section describes the experimental methodologies for testing our prototype. Each participant followed this methodology in a similar way.

	Stage	Time
1	Introduction	2 minutes
2	Augmented Crutches	5 minutes
3	Projected Gait training	5 minutes
4	Questionnaire	3 minutes

Table 3. Augmented Crutches evaluation stage

The average time spent with each participant was approximately fifteen minutes. As we can observe in Table 3, the test was composed of four stages:

1. Introduction

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.

2. Augmented Crutches

The second task, performed by all participants, was to experiment with the system and follow the visual cues.

3. Projected Gait training

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 (essentially the footprint and the crutch icon as exemplified in Figure 31).

4. Questionnaire

Users were interviewed after each session and filled-in a small questionnaire. An observer (myself) 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. The questionnaire and answers of these participants are available in Appendix C.

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.

5.2 Performance task

Each participant was asked to replicate the projected gait training. Each exercise consisted of different visual cues combinations according to the different stage of rehabilitation according to the amount of weight in the injured leg. In the Augmented crutches phase, the user would first answer to the questions and then be presented with projected visual cues which introduce a guide of the components. More specifically, projected on the floor. The users didn't have any practice of the gait training exercise of our system in order for us to observe the first reaction to see if the projection was easy to understand. Under this circumstance we had to record interactions with video to then take conclusions with the help of observation in loco.

5.3 Participants

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 19 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.

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

Table 4. Participants' characteristics.



Fig. 31. Participant testing (example)

5.4 Results and Discussion

5.4.1 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 did not understand clearly through the image what was the type of crutch that is required”*. The problem here is if the user does not employ a forearm crutch (Figure 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 Figure 32.

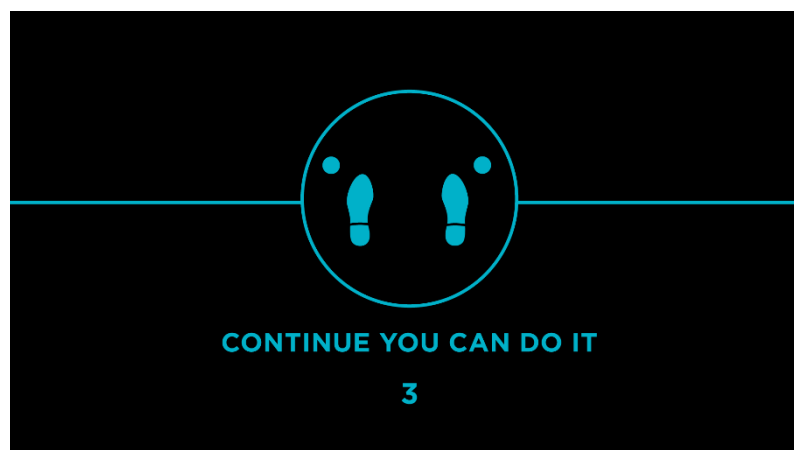


Fig. 32. Augmented Crutches’ motivating visual cue (an example).

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.

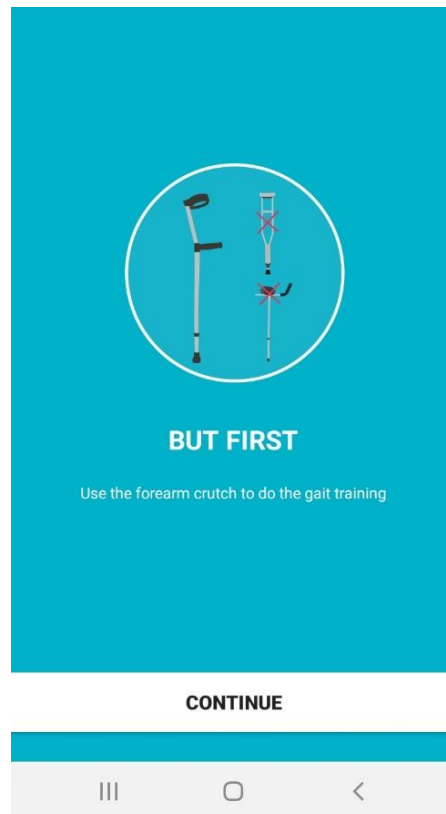


Fig. 33. Use forearm crutch. (an example)

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.

5.4.2 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”* (U9⁵). Other users are also inline with this motivating

⁵ Throughout this section, *Ui* refers to the user (i.e. the participant’s ID in our evaluation).

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.

Considering this last suggestion of user in the application that was create in Android Studio was added a screen were the user can choose if want to change the timing or not making more slow or fast. First, the user test the gait training with the automatic number of timing after this the user can change or not this timing if is to slow or fast , the timing can change to 5 seg, 10 seg , 20 seg .

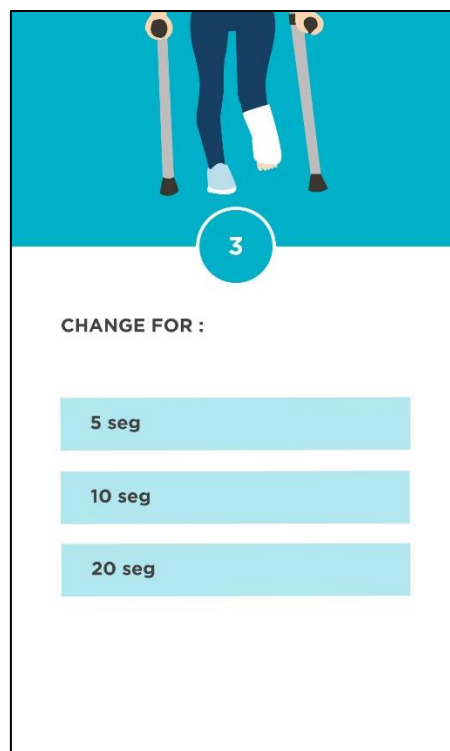


Fig. 34. Augmented Crutches' changing timing (an example)

5.4.3 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).

5.4.4 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.

5.4.5 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.

5.5 Validation with Physical Therapist

A professional physical therapist, besides the test subjects, also tested the Augmented Crutches prototype, performing three exercises, each one according to one gait training, to be sure that all gait training types were correct.

This expert feedback was afterwards gathered in an interview as a qualitative evaluation of the proposed solution.

First of all, this prototype's main vision was to prove we were able to guide subjects through projected gait training, so that the users would know how to walk with crutches properly. With this in mind, we wanted to evaluate the usefulness of this tool with physical therapist to make sure that was correctly set up for users to performed the walking with crutches correctly when they are alone or without supervision.

We also wanted to understand what would be missing to make Augmented Crutches a more complete tool for a common use along this field of rehabilitation.

We will now present the most significant feedback, stressing both the positive and negative aspects of the proposed solution.

- **Questions easy to understand**

The questionnaire of Augmented Crutches considers the way the questions should be made to be understood by users. Since this prototype focused on guiding the users to walk correctly with crutches when they are not taught or without supervision, the words used are intuitive and easy to understand being well connected each gait training.

Taking into account that for example in the question of "How much weight you can put in the injured side" the word "Total" means when the person already can put all the weight on the injured side but still need some support. The word "Some" means when

the person can put as the word said some weight. It's easier to understand the words than percentages because the use of percentages is more medical language and could easily mislead the users.

- **Adjust the height of crutch fundamental**

Before the gait training it is fundamental to adjust the height of crutch according to the height of the person, so that the person does not have any postural problem in the future because of using crutches. It is a recurring problem observed by the physiotherapist (not having the height of the crutches adjusted)

- **A great tool to guide the users to walk with crutches**

When someone does not have a Physical Therapist they do not know how to walk with crutches and most of the time when they go to rehabilitation with Physical Therapist the Physical Therapist always has to correct the person when walking with crutches but when they go home the physical therapist knows that people forget how to walk with crutches .

This would be a guide for the users when they are alone avoiding the incorrect walking with crutches have a base of how to walk with crutches avoiding confusion and no longer doing the coordination or position of the crutches incorrectly and not aggravate injured zone considering that by putting the crutch incorrect can live all the weight on the injured zone and that can make worse.

- **Potential useful tool for Physiotherapy**

While in Physiotherapy, the physical therapist often has to show to the patient how to walk with crutches and sometimes they have to repeat the movement so that the patient can understand how to walk with crutches. Tools like Augmented Crutches could help the physical therapist through the help of projected visual cues (gait training) to show how they should walk with crutches in a more easy way to understand instead of using verbal instructions, especially when the patient could understand better and would easier learn the gait training by showing an image, making also the work of physical therapist more easier.

Additionally, with the three-gait training that are in the application Augmented crutches could offer a fourth gait training for Physical Therapist. This gait training is advance the two crutches at the same time then the injured foot and then good foot Depending on the patient and what the doctor said the physiotherapists show this gait training. This gait training would be before the one in the option “Some” presented in the app Because is something that is adapted by the physiotherapist depending of the patient Augmented Crutches presents only three gait training.

5.6 Summary

In this chapter we introduced the validation of a physical therapist Firstly, the description of the testing of Augmented Crutches with the physical therapist, followed by the three exercises according to each one of the gait training. Secondly, we described the expert feedback of the proposed solution

Conclusion 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.

This projected was not focus to be use by older people because of the use of the technologies that for then could be a problem because of that our testing was to people from 19 years to 57 years however we would like to in the future to the testing to older people because also them can have difficulties walking with crutches.

At this point there is nothing to say that the person is doing the correct sequence or not. In future work one could add movement detection for the person to have more feedback and to know that she/he is performing the correct sequence, and then compare that without using the projector to assess if people had learned and how much time they would take to learn with the help of the projector as well as the improvements.

References

1. Li, S., Armstrong, C., Cipriani, D.: A Three-point gait crutch walking: Variability in ground reaction force during weight bearing. *Archives of Physical Medicine and Rehabilitation*, 82 (1), pp. 86-92 (2001).
2. Tsuda, N., Tarao, S., Nomura, Y., Kato, N.: 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 (2018).
3. Vitório, R., Lirani-Silva, E., Pierucinni-Faria, F., Moraes, R., Gobbi, L.T, Almeida, Q. J.: Visual cues and gait improvement in Parkinson's disease: Which piece of information is really important? *Neuroscience*, 277, pp. 273-280 (2014).
4. Sidaway, B., Anderson, J., Danielson, G., Martin, L., Smith, G.: Effects of long-term gait training using visual cues in an individual with Parkinson disease. *Phys Ther.*. Feb; 86 (2), pp.186-94 (2006).
5. Sodhi, R., Benko, H., Wilson, A.: LightGuide: projected visualizations for hand movement guidance. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'12)*. ACM, New York, NY, USA, 179-188 (2012).
6. Rehawalk homepage, <https://samcon.nl/Rehabilitation/Gait-rehab/Zebris-Rehawalk>, last accessed 2019/05/03.
7. Sekhavat, Y., Namani, M.: Projection-Based AR: Effective Visual Feedback in Gait Rehabilitation. *IEEE Transactions on Human-Machine Systems*, pp. 1-11 (2018).
8. Delden, R. V., Janssen, J., Stal, S. T., Deenik, D., Meijer, W., Reidsma, D., Heylen, D.: Personalization of Gait Rehabilitation Games on a Pressure Sensitive Interactive LED Floor. In R. Orji, M. Reisinger, M. Busch, A. Dijkstra, A. Stibe, M. Tscheligi (eds.): *Proceedings of the Personalization in Persuasive Technology Workshop, Persuasive Technology 2016*, Salzburg, Austria, 05-04-2016, published at <http://ceur-ws.org> (2016).

9. Kim, S. J., Mugisha, D.: Effect of explicit visual feedback distortion on human gait. *Journal of Neuroengineering Rehabilitation*. Apr 28; 11:74 (2014).
10. Merrett, G., Ettabib, M., Peters, C., Hallett, G., White, N.: Augmenting forearm crutches with wireless sensors for lower limb rehabilitation. *Measurement Science and Technology*, 21(12) (2010).
11. Kahneman, D.: *Thinking, fast and slow*. New York: Farrar, Straus and Giroux (2011).
12. Reitberger, W., Tscheligi, M., de Ruyter, B., Markopoulos, P.: Surrounded by ambient persuasion. In *CHI'08 Extended Abstracts on Human Factors in Computing Systems (CHI EA'08)*. ACM, New York, NY, USA, pp. 3989-3992 (2008).
13. Jessen, J., Lund, H., and Jessen, C.: Physical computer games for motivating physical play among elderly. *Gerontechnology*, 13(2):220-220 (2014).
14. Lund, H., Jessen, J.: Effects of short-term training of community-dwelling elderly with modular interactive tiles. *Games for health journal*, 3(5):1-7 (2014).
15. Lund, H.: Modular interactive tiles for rehabilitation: Evidence and effect. In *Proc. ACS'10*, pp. 520-525 (2010).
16. Tabak, M., Hermens, J., Burkow, T., Ciobanu, L., Berteau, M.: Acceptance and usability of an ambulant activity coach for patients with COPD. In: *Proceedings of the IADIS international conference e-health*, Prague, 24–26 July, pp.61–68. IADIS Press (2013).
17. Youdas, J. W., Kotajarvi, B. J., Padgett, D. J., Kaufman, K. R.: Partial Weight-Bearing Gait Using Conventional Assistive Devices. *Arch Phys Med Rehabil*. 2005 Mar; 86(3):394-8 (2005).
18. Goh, J. C., Toh, S. L., Bose, K.: Biomechanical study on axillary crutches during single-leg swing-through gait. *Prosthetics & Orthotics International*, 10:89-95 (1986).
19. Carpentier, C., Font-Llagunes, J., Kövecses, J.: Dynamics and Energetics of Impacts in Crutch Walking. *Journal of applied biomechanics* 26(4):473-483 (2010).
20. Sammer, G., Uhlmann, T., Unbehau, W., Millonig, A., Mandl, B., Dangschat, J., Mayr, R.: Identification of Mobility-Impaired Persons and Analysis of Their Travel Behavior and Needs. *Transportation Research Record.*, 2320, 46–54 (2013).
21. Cowan, R. E., Fregly, B. J., Boninger, M. L., Chan, L., Rodgers, M.: Reinkensmeyer DJ: Recent trends in assistive technology for mobility. *Journal of Neuroengineering and Rehabilitation*, 9 (20), pp. 9-20 (2012).

22. Campos P., Nunes N. J.: Principles and Practice of Work Style Modeling: Sketching Design Tools. In: Clemmensen T., Campos P., Orngreen R., Pejtersen A.M., Wong W. (eds) *Human Work Interaction Design: Designing for Human Work*. HWID 2006. IFIP International Federation for Information Processing, vol 221. Springer, Boston, MA (2006).
23. Tyson, S. F., Rogerson, L.: Assistive walking devices in non-ambulant patients undergoing rehabilitation after stroke: the effects on functional mobility, walking impairments and patients' opinion. *Archives of Physical Medicine and Rehabilitation*, 90, 475–479 (2009).
24. Rose, J., Cahill-Rowley, K., Butler, E.: Artificial walking technologies to improve gait in cerebral palsy: multichannel neuromuscular stimulation. *Artificial Organs*, 41(11), E233–E239, (2017).
25. Chamorro-Moriana, G., Sevillano, J., Fernández, C.: A Compact Forearm Crutch Based on Force Sensors for Aided Gait: Reliability and Validity. *Sensors (Basel)* , 16(6): 925. (2016)
26. Merians, A. S., Jack, D., Boian, R., Tremaine, M., Burdea, G. C., Adamovich, S. V., Recce, M., Poizner, H.: Virtual reality-augmented rehabilitation for patients following stroke. *Physical Therapy* (82), 898–915 (2002).
27. Jessen, J., Lund, H., Jessen, C.: Physical computer games for motivating physical play among elderly. *Gerontechnology*, 13(2):220-220 (2014).
28. Constantine, L., Campos, P.: CanonSketch and TaskSketch: Innovative Modeling Tools for Usage-Centered Design. In *OOPSLA'05*, October 16-20, San Diego, USA. (2005).
29. Luo, X., Kline, T., Fischer, H., Stubblefield, K., Kenyon, R., Kamper, D.: Integration of augmented reality and assistive devices for post-stroke hand opening rehabilitation. *International Conference of the IEEE Engineering in Medicine and Biology Society*, Shanghai, China (2005).
30. Schlick, C., Ernst, A., Bötzel, K., Plate, A., Pelykh, O., Ilmberger, J.: Visual cues combined with treadmill training to improve gait performance in Parkinson's disease: A pilot randomized controlled trial. *Clinical rehabilitation*, 30 (2015).

31. Azulay, J. P., Mesure, S., Blin, O.: Influence of visual cues on gait in Parkinson's disease: Contribution to attention or sensory dependence? *Journal of the neurological sciences*, (2006).
32. Fok, P., Farrell, M., McMeeken, J., Kuo, Y. L.: The effects of verbal instructions on gait in people with Parkinson's disease: a systematic review of randomized and non-randomized trials. *Clinical rehabilitation*, 25(5):396-407. DOI:10.1177/0269215510387648. (2011).
33. Hayashi, A., Nagaoka, M., Yoshikuni, M.: Music therapy in Parkinson's disease: Improvement of Parkinsonian gait and depression with rhythmic auditory stimulation. *Parkinsonism & Related Disorders*, 12. 10.1016/j.parkreldis.2006.05.026 (2006).
34. Thaut, M., McIntosh, G., Rice, R., Miller, R., Rathbun, J., Brault, J.: Rhythmic Auditory Stimulation in Gait Training for Parkinson's Disease Patients. *Mov Disord*, 11(2):193-200, (1996).
35. Ledger, S., Galvin, R., Lynch, D., Stokes E.K.: A randomised controlled trial evaluating the effect of an individual auditory cueing device on freezing and gait speed in people with Parkinson's disease. *BMC neurology*, 8, 46. doi:10.1186/1471-2377-8-46 (2008).
36. Suteerawattananon, M., Morris, G. S., Etnyre, B. R., Jankovic, J., Protas, E. J.: Effects of visual and auditory cues on gait in individuals with Parkinson's disease. *Journal of the Neurological Sciences*, 219(1), 63-69 (2004).
37. Luessi, F., Mueller, L. K., Breimhorst, M., Vogt, T.: Influence of visual cues on gait in Parkinson's disease during treadmill walking at multiple velocities. *Journal of the Neurological Sciences*, 314(1-2):78-82. DOI:10.1016/j.jns.2011.10.027, (2012).
38. Ferrarin, M., Brambilla, M., Garavello, L., Di Candia, A., Pedotti, A., Rabuffetti, M.: Microprocessor-controlled optical stimulating device to improve the gait of patients with Parkinson's disease. *Med Biol Eng Comput* . 42(3):328-32 (2004).
39. Maximilien, M. and Campos, P.: Facts, Trends and Challenges in Modern Software Development. *Int. J. Agile and Extreme Software Development*, Vol. 1, 1, (2012).
40. McCandless, P. J., Evans, B. J., Janssen, J., Selfe, J., Churchill, A., & Richards, J.: Effect of three cueing devices for people with Parkinson's disease with gait initiation difficulties. *Gait & posture*, 44, 7–11. doi: 10.1016/j.gaitpost.2015.11.006 (2005).

41. van Wegen E., de Goede, C., Lim, I., Rietberg, M., Nieuwboer, A., Willems, A., Jones, D., Rochester, L., Hetherington, V., Berendse, H., Zijlmans, J., Wolters, E., Kwakkel, G.: The effect of rhythmic somatosensory cueing on gait in patients with Parkinson's disease. *Journal of the Neurological Sciences*, 248(1), 210–214 (2006).
42. Reis, S., Correia, N. : An Imaginary friend that connects with the user's emotions. In ACE' 11 Advances in Computer Entertainment Technology . ACM, Lisbon, PT, (2011).
43. Peres, B. , Campos, P., Azadegan, A.: A Persuasive Approach in Using Visual Cues to Facilitate Mobility Using Forearm Crutches. In *Persuasive'19 Behavior Change Support Systems (BCSS@PERSUASIVE)*. Limassol, CY, (2019)
44. Peres, B. , Campos, P., Azadegan, A.: Digitally Augmenting the Physical Ground Space with Timed Visual Cues for Crutch-Assisted Walking . In *CHI'19 Extended Abstracts on Human Factors in Computing Systems (CHI EA'19)*. ACM, Glasgow, UK, (2019).
45. Peres, B., Campos, P., Azadegan, A.: *A Digitally-Augmented Ground Space with Timed Visual Cues for Facilitating Forearm Crutches' Mobility*. In *Interact'19 (INTERACT(1))*. Paphos , CY, (2019)

Appendix A

A.1 Questionnaire to Physical Therapists

1. What is the biggest problem that people have when they are walking with crutches?

2. How many types of gait training they normally have to do?

3. With this , the position and coordination is fundamental ?

4. People have difficulties in understand the position and coordination of crutches?

A.2 Answers from the questionnaire

1.

Physical Therapist 1: It depends a bit from person to person but overall it is the position and coordination of the crutches and the foot (the sequence of the movements). People do not know which goes first, if it is the foot, if it is the crutch, it is usually the main complaint of people.

Physical Therapist 2: Normally people have difficulties in the coordination of the feet and the crutch they do a lot of confusion.

2.

Physical Therapist 1 : It depends, however there are three ways: First ,three points (this is when one can't put any weight on injured foot and the foot cannot be on the floor) that is two crutches at the same time to the front then the good foot, the injured foot goes simultaneously with the good foot, then Four-points (when one can put some weight) is first the crutch on the good side and the injured foot and then the crutch on the injured side and the good foot and finally when one can put all the weight on the injured side depending on the patient and what the doctor said it is used only a crutch, the crutch should be on the opposite side of the injured side and is first the crutch and injured foot then good foot. People need one crutch when they still need some support. However sometimes it is necessary another way of walking before the one that I explain in some weight when the user still does not feel very comfortable to walk crutches or because the doctor said that is the two crutches to the front then injured foot then good foot , at this moment the injured foot can go to the floor

Physical Therapist 2: It depends on the patient and what the doctor said but there are three ways: At the beginning is the two crutches at the same time and then good foot the injured foot simultaneously with good foot, then on the middle of recovery when can already put some weight is : a crutch on the good side and foot injured then crutch on the injured side and good foot and finally in the end when can put all weight is only

a crutch on the opposite side of the injured side and is first the crutch and injured foot then good foot.

3.

Physical Therapist 1 : Yes, yes, in terms of position and coordination, it is critical to not put all the weight on the injured side so that the whole weight does not fall on top of the injured leg, aggravating the injury. As an example, consider someone who mistakes the position of the crutches and first places the “good” foot down, leaving all the weight on the injured side, this would be enough to worsen the injury.

Physical Therapist 2: yes, to not put all the weight in the injured leg

4.

Physical Therapist 1 : they confuse a lot since they never know which one (crutch) goes first, mostly forget because of that and especially the people with more age gives up and they have to use other walking assistances.

Physical Therapist 2: yes people had difficulties in understand the coordination and position they make confusions not knowing which one go first and when they arrive to physiotherapy they normally walk incorrectly and then we taught them how to walk correctly but they confuse and then when they go home and arrive again they are normally walking incorrectly again because they forget and they walk how they taught was correct.

Appendix B

B.1 Questionnaire to Users that walk with crutches

1. Gender *

Marcar apenas uma oval.

- ☐ F
☐ M

2. Age *

3. Country *

4. Have you ever walked with crutches? *

Marcar apenas uma oval.

- ☐ Yes
☐ No

5. Were you taught on how to walk with crutches?

Marcar apenas uma oval.

- ☐ Yes
☐ No

6. If not, how did you know you were correctly walking with the crutches?

7. Did you experience difficulties walking with crutches?

Marcar apenas uma oval.

☐ Yes

☐ No

8. If yes:

Marcar tudo o que for aplicável.

☐ Position of the crutches / Coordination Difficulties

☐ Balance Difficulties

☐ Adaptation Difficulties

☐ Distance of the crutches in relation to the foot

☐ Muscular pain (arms and hands)

☐ Other difficulties (please describe)

9. Other difficulties:

Thank you for your feedback

Com tecnologia

 Google Forms

B.2 Answers from the questionnaire

118 participants (33 female , 85 male) between 19- 57 years old from around the globe (Portugal , Italia , Brazil , UK , France , Spain Scotland and Canada) also to conclude if was global problem or not . All the participants already walk at least one time with crutches.

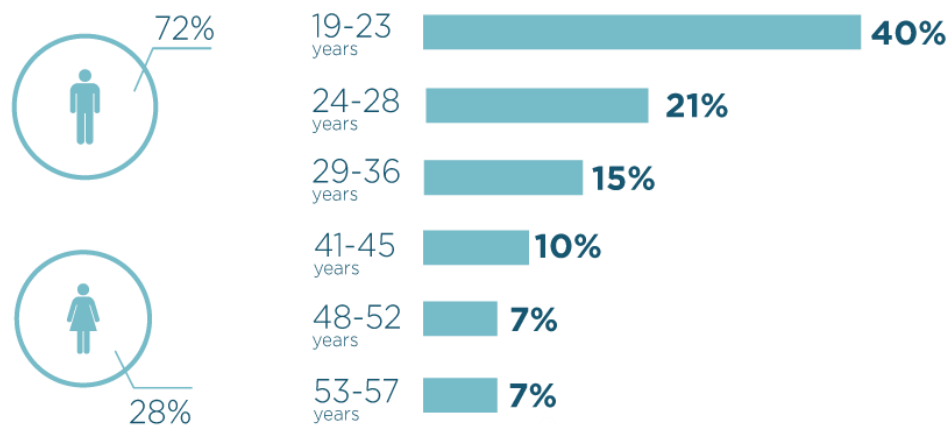


Fig. 35. Age and gender of participants

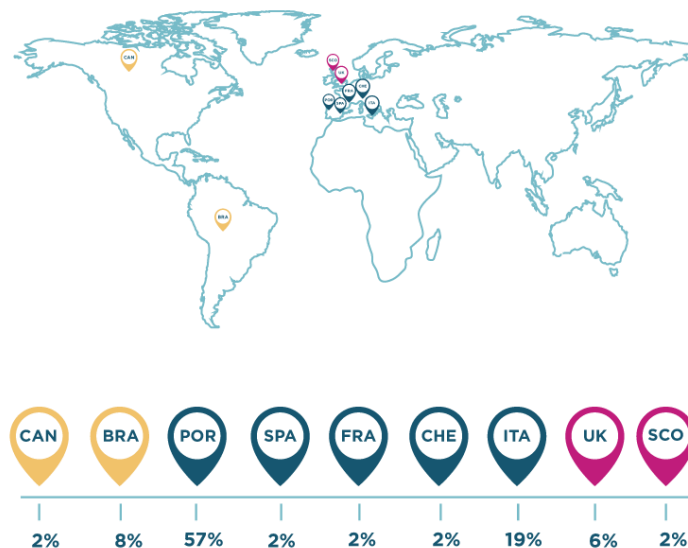


Fig. 36. Country of participants

Being taught on walking with crutches, 51% answers that were not taught on how to walk with crutches. 51% of participants said what they did to know how to walk with crutches, the most common answers were: "I didn't" (20%) , "Looked for the most

comfortable way to walk for me”(15%) , “By watching others”(15%) , “ I don’t know” (12,5%) , “ Trial and error” (10%) , “ Intuition” (12,5%). With this we conclude that not everyone is taught to walk with crutches and that people feel a little bit lost because they don’t have any information and do not know how to walk correctly with crutches.

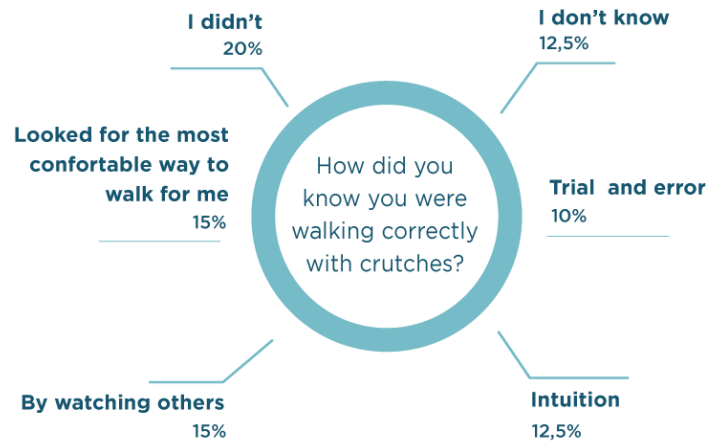


Fig. 37 Answers of participants about how they know how to walk with crutches

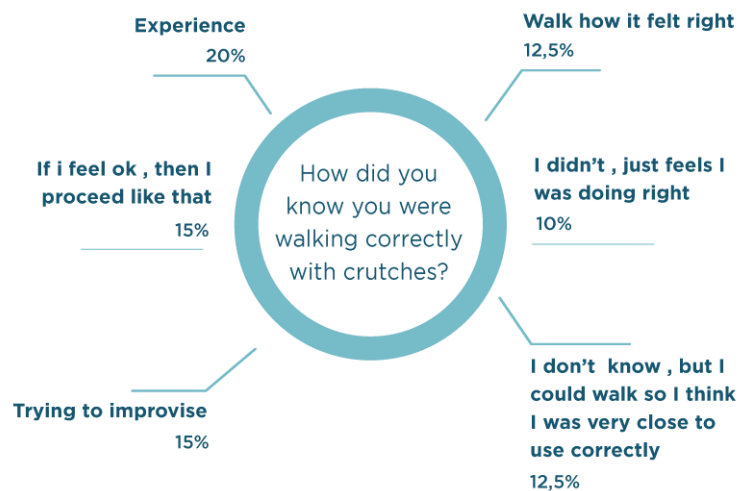


Fig. 38. Answers of participants about how they know how to walk with crutches

Regarding to difficulties on walking with crutches was conclude that users feel difficulty in walking with crutches being their taught or not they continue to feel difficulties in walking with crutches. The biggest difficulty that they feel is the position and coordination between the foot and crutches.

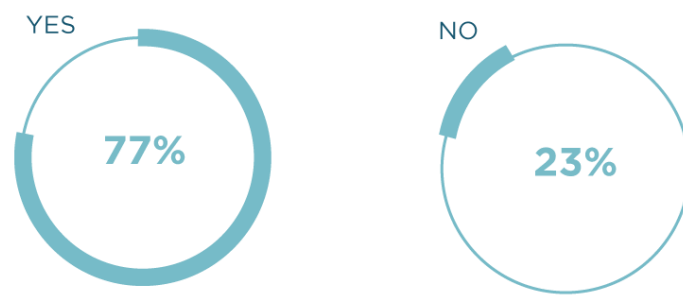


Fig. 39. Difficulties on walking with crutches

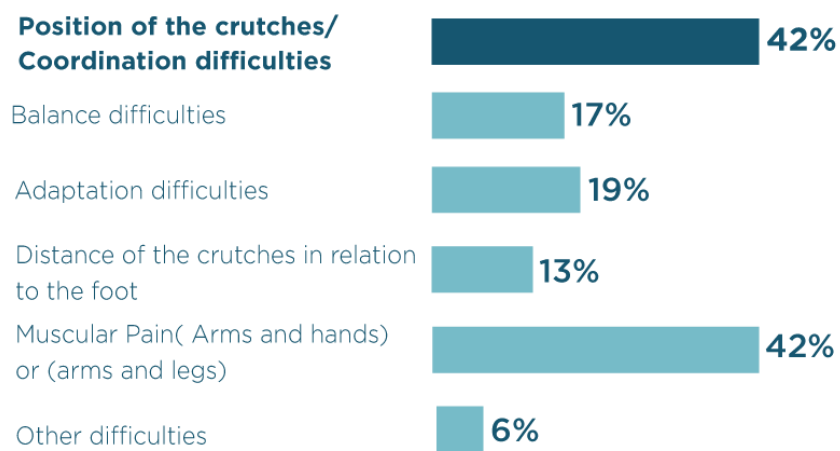


Fig. 40. Type of difficulties

Appendix C

C.1 Questionnaire to Participants of Augmented Crutches

1. Gender?

Marcar apenas uma oval.

☐ F

☐ M

2. Age?

3. Experience on walking with crutches?

Marcar apenas uma oval.

☐ Yes

☐ No

4. Feel difficulties in understand the display of visual cues?

Marcar apenas uma oval.

☐ Yes

☐ No

5. Why?

6. What do you think about the timing?

7. What do you think about the sentence Continue You Can Do It?

Com tecnologia



C.2 Answers from the questionnaire

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

Fig. 41. Type of difficulties

Subject	Feel difficulties in understand the display of visual cues?	Why
U1	No	Positioning, and coordination of the solution was easy to use
U2	No	Positioning, and coordination of the solution was easy to use
U3	No	Positioning, and coordination of the solution was easy to use
U4	No	Positioning, and coordination of the solution was easy to use The numbers helped

U5	Yes a little	<p>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</p> <p>being a little confusing at the beginning</p>
U6	No	<p>Positioning, and coordination of the solution was easy to use</p> <p>The numbers helped</p>
U7	No	<p>This is useful for understanding the crutch walking process</p> <p>The numbers helped</p> <p>Positioning, and coordination of the solution was easy to use</p>
U8	Yes a little in the beginning	<p>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</p> <p>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"</p> <p>Without this I do not know if I could feel confident enough on how to walk with crutches</p> <p>being a little confusing at the beginning</p>
U9	No	<p>Positioning, and coordination of the solution was easy to use</p> <p>The numbers helped</p>
U10	No	<p>The projection was easy to understand</p> <p>The numbers helped</p>
U11	No	<p>the projection helps you see the sequence and what goes first</p> <p>The display of visual cues with numbers helped</p>
U12	No	<p>Positioning, and coordination of the solution was easy to understand</p> <p>The numbers of visual cues helped</p>

U13	No	The display of visual cues with numbers helped being a little confusing at the beginning because once I moved the foot, the positioning of the image changed
U14	No	The numbers helped The display of visual cues was easy to understand
U15	No	The numbers helped The display of visual cues was easy to understand
U16	No	The numbers helped
U17	No	The numbers helped
U18	No	The display of visual cues was easy to understand
U19	No	The display of visual cues was easy to understand The numbers helped
U20	No	The display of visual cues was easy to understand
U21	No	The display of visual cues was easy to understand

Fig. 42. Feel difficulties in understand the display of visual cues?

Subject	What do you think about the timing?	The sentence Continue You Can Do It
U1	timer also aims to encourage the person to learn to walk better with crutches	It's a good sentence to do a pause in walking with crutches and to rest It's a sentence that encourage to continue to walk with crutches
U2	Regarding to the timing I felt that 15 seg was a good timer to learn how to walk with crutches and also encourage to walk with crutches	It's a good sentence to do a pause in walking with crutches and to rest
U3	make the timing intervals defined by each user, according to the training experience	It's a sentence that encourage to continue to walk with crutches

U4	Regarding to the timer I would gamify the system and Maybe instead of showing different timings because only show one timing , [the system] could present different challenges: stairs, ramps	It's a good sentence to do a pause in walking with crutches and to rest
U5	For me, It is too fast	It's a good sentence to do a pause in walking with crutches and to rest
U6	make the timing intervals defined by each user, according to the training experience	It's a good sentence to do a pause in walking with crutches and to rest
U7	was a good timing to learn how to walk with crutches and also encourage to walk with crutches	It's a good sentence to do a pause in walking with crutches and to rest It's a sentence that encourage to continue to walk with crutches
U8	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	It's a sentence that encourage to continue to walk with crutches
U9	-It is too fast, it requires some speed to perform the position of the visual cues timer also aims to encourage the person to learn to walk better with crutches	It's a good sentence to do a pause in walking with crutches and to rest It's a sentence that encourage to continue to walk with crutches
U10	Without the timer, it would be monotonous was a good timing to learn how to walk with crutches and also encourage to walk with crutches for me was good not to slow	It's a good sentence to do a pause in walking with crutches
U11	was a good timing to learn how to walk with crutches and also encourage to walk with crutches	It's a good sentence to do a pause in walking with crutches and to rest it
U12	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	It's a sentence that encourage to continue to walk with crutches
U13	For me, It is too fast I would add more time	It's a good sentence to do a pause in walking with crutches

U14	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	It's a sentence that encourage to continue to walk with crutches
U15	It is too fast, it requires some speed to perform the position of the visual cues	It's a good sentence to do a pause in walking with crutches
U16	Regarding to the timing I felt that 15 seg was a good timer to learn how to walk with crutches and also encourage to walk with crutches Without the timer, it would be monotonous	It's a good sentence to do a pause in walking with crutches
U17	Regarding to the timing I felt that 15 seg was a good timer	It's a sentence that encourage to continue to walk with crutches and to not give up
U18	Without the timer, it would be monotonous With the timer, to learn how to walk with crutches and also encourage to walk with crutches	It's a good sentence to do a pause in walking with crutches
U19	With the timer, to learn how to walk with crutches and also encourage to walk with crutches Regarding to the timing I felt that 15 seg was a good timer	It's a good sentence to do a pause in walking with crutches
U20	Regarding to the timing I felt that 15 seg was a good timer	It's a sentence good to do a pause in walking with crutches and to encourage to continue to walk with crutches
U21	With the timer, to learn how to walk with crutches and also encourage to walk with crutches Without the timer, it would be monotonous	It's a sentence that encourage to continue to walk with crutches and to do a pause

Fig. 43. What do you think about the timing? And The sentence Continue You Can Do