NOTIFICATION, GAMIFICATION AND CUEING IN MOBILE HEALTH APPLICATIONS

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Abstract

Notification, gamification and cueing in mobile health applications

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Lack of physical activity is prevalent in today's society despite the fact that not getting enough physical activity contributes to different physical and mental conditions. Exercises are also used as physical therapy for various injuries and disabilities. Yet, many people do not commit to regular exercise routines or frequently do not adhere to their rehabilitation routines due to difficulties with scheduling regular appointments with professionals, the high expenses of personal trainers and physical therapists, and even just boredom with the prescribed regimens.

In this dissertation, we first studied the impact of push notifications and gamification on people's motivation for doing regular exercises. To do this we developed a fitness mobile application, *5 mins* with the ability to send custom reminder push notifications. In a preliminary study we evaluated the effectiveness of reminder push notifications on performing fitness exercises.

In addition, we investigated the effect of multimodal cueing mechanisms on physiotherapy exercises. We developed a wrist rehabilitation mobile application that works with the Neblina^{TM} wearable sensor. A user study with 10 users was done to assess the impact of gamification and cueing on subjects' performance of basic wrist rehabilitation exercises.

The result of our experiments show the importance of fine-tuning both notifications and cueing strategies in exercise and rehabilitation. Whereas well-timed notifications and multimodal cueing can provide motivation and help encourage an end-user, poor methods may discourage users from being active and performing their exercises correctly.

Acknowledgments

I am deeply grateful to Dr. Marta Kersten-Oertel, my supervisor for providing me with the opportunity to study in her laboratory. Her moral support, patience, and assistance through my education is unforgettable. I could not have had a better mentor and role model. Besides my supervisor, I would like to thank my fellow labmates in the Applied Perception Lab for sharing their expertise and knowledge and providing a friendly environment to do research in. Last but not least, I would like to thank my supportive family and friends for supporting me spiritually through my life. Any attempt at any level cannot be completed without their encouragement and guidance.

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Chapter 1

Introduction

There is overwhelming evidence that physical activities improve both physical and mental well-being. Regular workouts can reduce the risk of many diseases such as heart problems and strokes, diabetes and mental health problems. Advances in mobile devices have made possible the adherence to healthy lifestyles and workout routines with less supervision from professionals, for example, a strength trainer or physiotherapist. Moreover, mobile health applications can help individuals with chronic conditions and disabilities who require physiotherapy and rehabilitation to stay motivated and encouraged during their physiotherapy process.

The term "mHealth" refers to the concept of using mobile devices, such as mobile phones, tablets, and smartphones, in medicine and public health [4]. The goal of mHealth is to provide information and resources for patients so they can manage their health better while reducing costs associated with health, fitness and rehabilitation. The functionality of mHealth applications may range from simple tasks such as tracking and recording health data to more complex ones like gathering motion data and providing guidance in the form of cueing and feedback in the context of different fitness activities. Based on a report from 2020 [5], the global Mobile Health (mHealth) market is forecast to reach 311.98 billion USD by 2027.

Owing to the ubiquitous nature of mobile devices, people tend to carry them throughout the day. Thus, the internal sensors of mobile devices can collect user's contextual data. As a result, the user can receive customized feedback based on their level of activity (e.g. reminders to do a workout) and context-aware reminders (e.g. location-based reminders) from mHealth applications. Ideally, these notifications are sent when it most likely to have a beneficial effect such as encourage the user to workout or take their medicine. Mobile devices can also wirelessly connect to wearable external devices that collect specific types of data from a particular body part (e.g. acceleration data from ankles). Although wearable and mHealth technologies have shown great potential in improving healthy lifestyles, they often have limited acceptance or short adoption rates. There are a number of reasons why this might be the case including poor interaction and user experience solutions, a lack of understanding of the data extracted by the sensors of these devices and the models and metrics conveyed to the end-user, and trust concerns on how and when the data is collected, how it is used and how it is stored.

In this dissertation, we address the shortcomings related to interaction and user experience solutions by exploring the impact of context-aware push notifications and gamification on encouraging users to be active and perform fitness routines and exercises. We developed a mobile fitness application, *5 Mins*, and performed a preliminary user study to investigate the effects of reminder push notifications on a user's level of physical activity. Furthermore, we looked at the effect of gamification and multimodal cueing mechanisms on physiotherapy exercises. To study this we conducted a user study with a custom developed mobile application, *Neblina Wrist Physio*, and a wearable motion sensor. The application uses a game intending to be enjoyable and fun to play, thus encouraging and motivating users to perform their wrist physiotherapy exercises.

1.1 Encouraging Healthy Habits with Reminders

Habits are defined as actions that are automatically triggered in response to contextual cues [6]. Automation requires repetition over time and more challenging habits demand more repetitions over a longer period of time [7]. There are two main steps for performing every task: (1) remembering to perform a task, and (2) being able to perform it. As mentioned above, an increasing majority of people tend to have their mobile devices or even smartwatches on them most of the time. Hence, these smart devices can be used as a means for receiving reminders. However, the context in which reminder push notifications occur is very important and can impact their effectiveness. Yet it is challenging for designers to determine when and how to deliver reminders to a user so that they are most effective. The first research goal of this work was to answer the following questions: *Which modality (visual, aural, haptic) is the most appropriate for a given notification in a given context?*, *When is the ideal time to receive a push notification?* and *What is the ideal device to receive a specific type of notification?* (Figure 1)

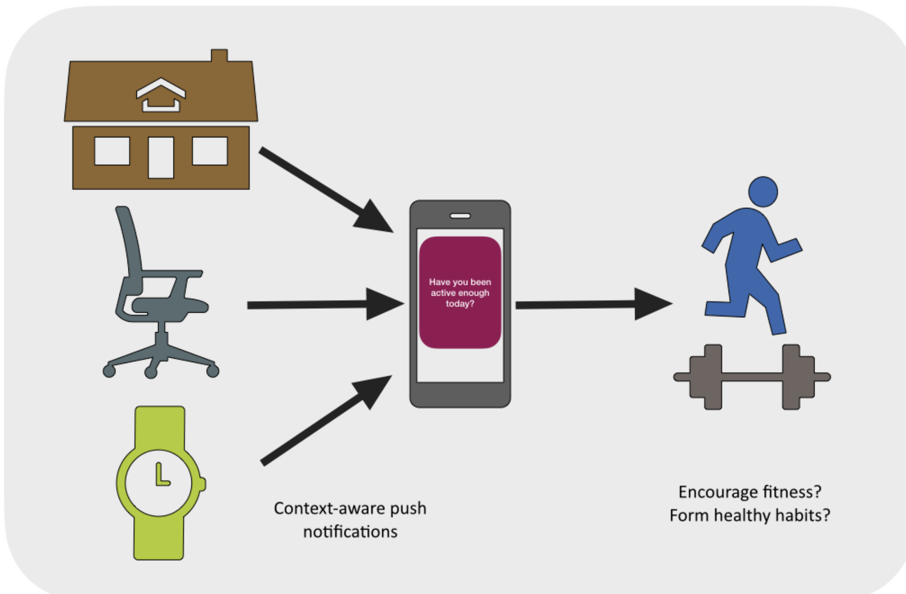

Figure 1: To explore the impact of context-aware reminder push notifications we designed a mobile fitness application with 3 types of reminders: location-based, activity-based (e.g. the user has not been active enough) and time-based (i.e. sent at a specific time each day. The application and results of a preliminary study are described in Chapter 4

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1.2 Multimodal Cueing in Physiotherapy

Cueing is defined as interventions in the form of guidance that are provided to help an individual to begin and continue a task. Cueing can be used to gain attention, break patterns and improve learning retention. Thus, it is recognized as one of the effective methods for improving users' performance during (physiotherapy) exercises. Traditionally, cueing is provided by a person using different means (e.g. instructional speech or demoing an exercise). However, this method requires consistent presence of a professional with the patient while performing exercises.

With the emergence of various technologies for collecting human motion data, many studies have been conducted regarding reducing the need for consistent supervision and cueing from a professional in the context of physiotherapy and rehabilitation. Furthermore, research on multimodal perception widely supports the claim that multimodal signals are more salient, easier to interpret, and are capable of more nuanced communication, relative to unimodal signals. In addition, advances in wearable motion sensors have made them a great tool to be used with mHealth applications for monitoring an individual while performing physiotherapy exercises.

One widely used method for keeping users motivated and encouraged during uninspiring and tiring processes like physiotherapy is to gamify the task. Gamification is defined as adding game elements to a non-game context in order to make a rather boring task more interesting. Thus, the second research goal of this work was to answer the following questions: *Which cueing modalities (no cueing, audio, visual, or a combination of audio and visual) are best to improve physiotherapy exercise quality in a gamified environment?* and *Do users have fun and become engaged in physiotherapy exercises when they are gamified?* (Figure 2)

1.3 Contributions

In the course of conducting this research, we explored the impact of context-aware push notifications in fitness applications, as well as, the impact of gamification and cueing in physiotherapy exercises. To explore the impact of push notifications on exercise motivation and adherence, we developed a custom iOS fitness application *5 Mins*. To explore the impact of gamification and cueing for physiotherapy, we developed a custom app that works with a wearable sensor (the Motsai Neblina^{TM}). User studies with these two custom applications were performed to determine the impact of varying push notifications, gamification and cueing on fitness and rehabilitation. The results of our survey with 105 participants suggest:

1. Visual push notifications are favoured in the context of work, home and fitness.

2. Smartphone users tend to favour being reminded to be more active; however,

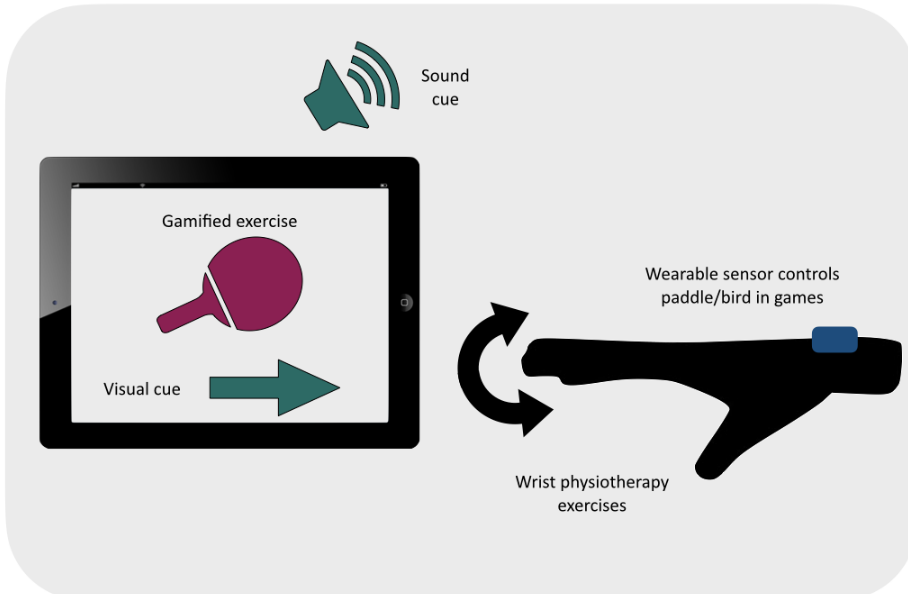


Figure 2: To explore the effect of gamification and cueing in physiotherapy we designed a mobile game that works with a wearable sensor for wrist physiotherapy exercises. We specifically looked at audio and visual cueing. The application and results of a preliminary study are described in Chapter 5

these reminders need to be received at times that the user has not been active enough.

3. Reminders are the most popular types of push notifications.

4. In the context of work, the ideal devices to receive notifications on are mobile devices and computers; however, regarding the context of home and fitness, people tend to receive their notifications on mobile devices and smartwatches.

The results of our preliminary study on the impact of context-aware push notifications on fitness activity showed that:

1. Reminders with dynamic content, the ability to retain daily workouts' history, and having gamified elements such as in-app rewards can lead to better app adaptation.

Our study on gamification and cueing in physiotherapy led us to conclude:

1. The use of gamification and cueing is effective in keeping users entertained and more engaged in physiotherapy exercises.

2. The impact of cueing modalities in improving the quality of gamified physiotherapy exercises is different based on the difficulty of the exercise and game.

1.4 Organization

The thesis is organized as follows. We begin by giving a background on push notifications, gamification, and habit formation in Chapter 2. In this chapter, previous work on the effect of push notifications and the connection between these types of notifications and building healthy habits are also reviewed.

In Chapter 3, we give a general definition of cueing and feedback and how these techniques can affect physical therapy. Further, we discuss wearable sensors and explore some of the previous health-related studies conducted using wearable sensors. Lastly, we introduce different cueing and feedback modalities and review previous related work in this area.

In Chapter 4, we present an experiment for evaluating the impact of push notifications on fitness. This chapter includes a description of our hypotheses, and a presentation of a user survey, a developed mobile fitness application, and the results of a preliminary user study.

Chapter 5 presents an experiment for investigating the effect of gamification and multimodal cueing on physiotherapy. In this chapter, we begin by giving a short description of the Neblina™ wearable sensor which is used in the user study. Next, the application and its intended use in wrist physiotherapy are defined. Lastly, we describe a user study that was conducted to look at the impact of gamification and cueing on physiotherapy and we summarize the results of the study.

Chapter 6 concludes the dissertation and discusses some of the potential avenues for future work in health and fitness.

Chapter 2

Push Notifications

Since the emergence of push technology in the mid-1990s, the use and impact of notifications on different areas, for example, advertising receptivity, anxiety and stress, and social engagement has been studied in the field of human-computer interaction. Push technology, which was introduced by PointCast, was originally developed to help users sync their emails and calendars from their desktop computers to their Blackberrys [8]. In 2009, Apple gave users its version of push notifications which at that time, focused on sending notifications so that users would enter an app and interact with it more often [9]. In 2013, Google introduced push notifications to browsers and since 2016, the setup process for third-party apps and browsers has been significantly simplified thus gaining more wide-spread use [10]. According to a 2018 study, in total 43.9% of iOS devices opt-in for app push notifications. However, this rate is higher in Android devices (91.1%) since they are automatically enrolled for push notifications unlike iOS devices [11]. Mobile push notifications, in particular, are a common means to send messages from a mobile application to the user's device. They can have different purposes, including reminders, promotional updates, and social media notifications. According to a study from 2014, on average, smartphone users receive 63.5 notifications per day [12], triggered either locally or remotely from a server. In this chapter, we explore the different aspects of push notifications and their use in the particular domain of health and fitness.

2.1 Push Notification Modalities

Mobile push notifications can be silent or use different modalities such as haptic, visual (i.e. LED on phone) and aural or a combination of these. A study by Masshadi *et al.* showed that using any modality, e.g. sound, light, and vibration or a combination of these increases the chance of interacting with the notification immediately rather than when none of these modalities are used [13]. However, different contexts, types of messages, timings, etc., demand the use of different modalities. Delivering a notification with the right modality can make the difference between the user attending to the message rather than ignoring it. In a field study with 10 participants, Mashadi *et al.* [13] found that on average a notification was 12x more likely to be attended to immediately if it had any modality (sound, vibration, LED light) accompanied with it. Among the mentioned modalities, the authors found that users liked to associate vibration and sound with important notifications. More interestingly, they found that while light is typically preferred for low priority notifications, the persistent nature of it as a modality was found useful in terms of attention-seeking in comparison to the temporal nature of sound and vibration.

2.2 Reminder Push Notifications

One of the most powerful types of mobile push notifications is reminders. Specifically, reminder notifications can be very useful in the context of health. They can remind users to take their medications [14], follow a specific dietary routine [15], or help the elderly with their daily activities [16].

Despite the potential of smartphone apps to motivate users, they will not be successful in doing so if users are not willing to effectively engage with them. Reminder notifications are one of the most popular types of push notifications that can encourage user interaction and engagement with mobile applications. While reminder notifications themselves may not contain much information, they can persist in a user's mind [17] and encourage them to interact with the app in the future.

One of the most popular contexts for reminders is fitness and health-related notifications. Freynecor *et al.* [15] examined the role of reminder notifications in a mobile app designed to support dietary change. They found that most people accepted the default times for notifications rather than setting them based on their lifestyle and daily routines. Further, the authors noted that reminders lost their persuasiveness over time if the notifications occurred at the same time and had the same content (Figure 3) [15].

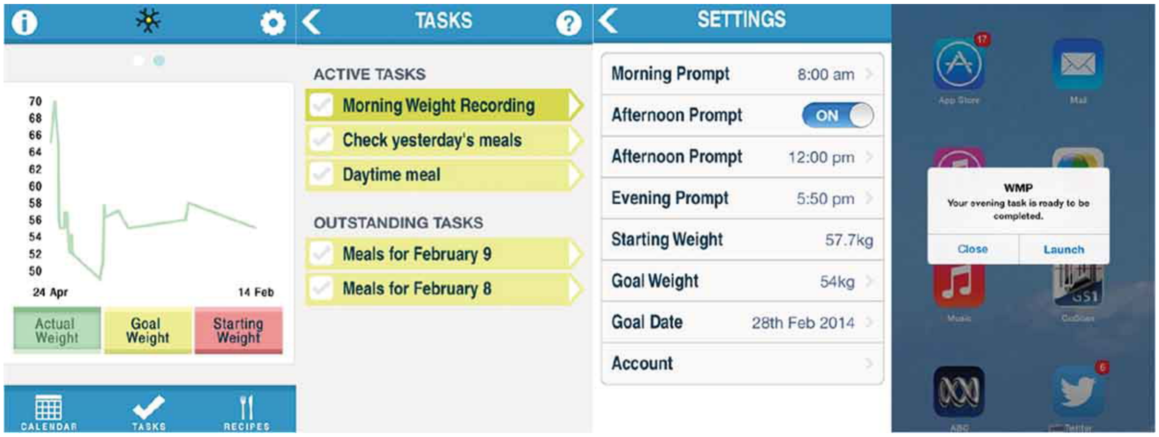


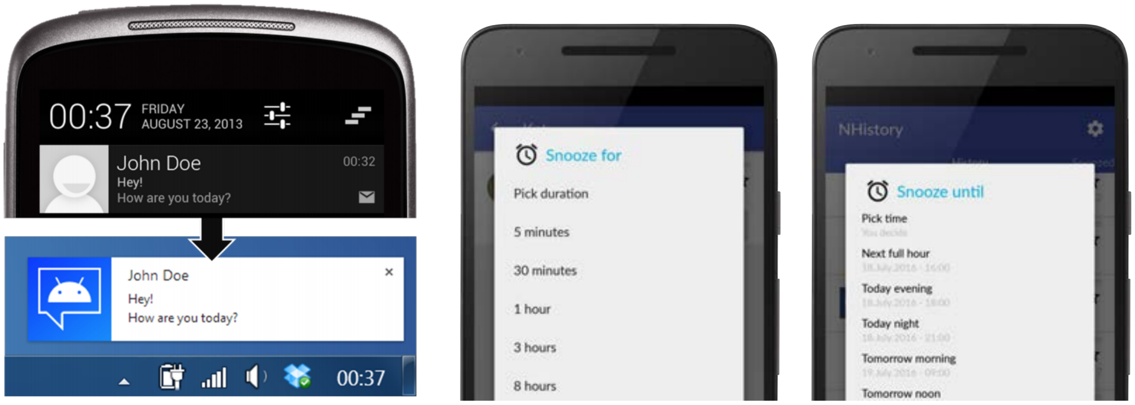
Figure 3: Screen shots of a dietary app from [15] with the ability to send reminder push notifications.

Bidargaddi *et al.* [18] developed a self-monitoring and health app to help users find their purpose in life by using daily self-monitoring and feedback strategies. They used push notifications as reminders for the user to open the app and record their behaviors and feelings. They found that sending push notifications containing a contextually tailored health message was associated with greater engagement with the app as compared to not sending any push notifications.

Vacca *et al.* [21] explored how mobile technology may be able to support mindfulness states. Each day, the user is prompted to commit to engaging in mindfulness activities and once they commit to practicing mindfulness, they are prompted (a maximum of three times per day) to direct their attention to their surroundings and feelings. The results showed that push notifications did elicit self-reflection in participants throughout the day and directed them to shift their attention to their current thoughts and environment (Figure 5).

2.3 Context-aware Notifications

Notifications vary in their level of importance based on their context. Communication applications, such as messengers, email, or social networks, rely on notifications to draw users' attention to new messages or content. This is often done by sending



(a) (b)

Figure 4: (a) The Android application and web browser plug-in that is used in [19] which automatically pushes notifications from a phone to a desktop computer; (b) The available snooze options in [20].

notifications about new posts or messages from friends, notifications about new "likes" of the user's own posts or notifications of events that friends have signed up for or are near the user. Indeed, in a large-scale study, Shirazi *et al.* [19] showed that users considered notifications about people and events to be important even if they did not require immediate attention. One of the main factors that result in notifications being considered unimportant is the frequency with which they are created (Figure 4a). Mehrota *et al.* [22] discussed how content and context of a notification can be used together in order to design intelligent non-disruptive notification mechanisms. After collecting and analyzing mobile notifications from 35 different users in 3 weeks, they developed a machine learning approach that predicts if a notification will be accepted or declined by the user based on the user's activity and the information contained in the notification. Specifically, they found out that a prediction model trained based on one user's personal data is able to work far better than a generic prediction model trained based on several users' data.

Some believe the ability to snooze mobile push notifications (Figure 4b) [20] or send them at identified breakpoints[23] can help reduce the negative effects of push notifications like distraction, and redundant stress and anxiety. Thus using intelligent and context-aware notifications (i.e. based on the user's current context, e.g. location, activity, etc.) is a potential solution to the problem of poorly timed notifications.

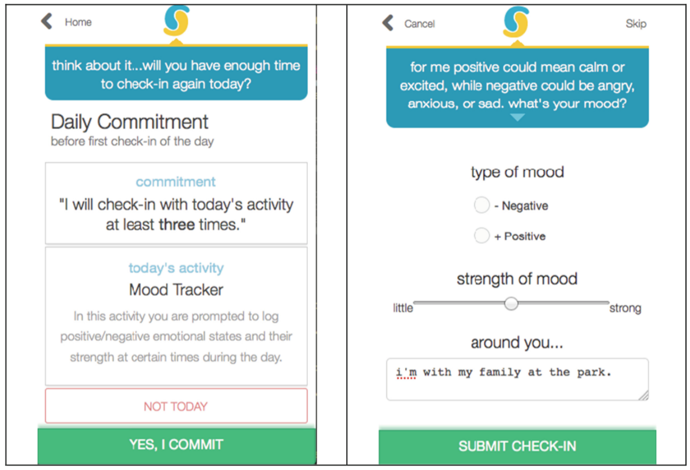


Figure 5: Screen shots of SIMA (Situated Interactive Mindfulness App) from [21]. After making a daily commitment (left) the user will be prompted with reminder push notifications to "check-in"(right).

2.4 Negative Effects of Push Notifications

While push notifications can have many advantages, such as making us feel more connected [24, 25], they can also have disadvantages. As mentioned above, one of the most negative aspects that comes from poorly timed notifications is that they can cause distraction, redundant stress and anxiety, and may result in the users deleting an app [26, 27, 17, 12, 28]. On the other hand, research has shown if notifications are novel, relevant and timely then users will be less negatively impacted by them [29]. There have been many studies that show the relationship between stress and the workload that is created by push notifications. For example, Westermann *et al.* [26] examined the relationship between push notification characteristics and settings, personality traits, technical affinity and stress caused by information and communication overload. They found that although notifications can provide valuable information, they can often be disturbing and are one of the main factors in creating techno-stress (i.e. stress associated with the overload of information and communication).

Besides, receiving push notifications at inopportune moments can become a source of interruption. Pielot *et al.* [12] showed that the amount of notifications received during a day is correlated with increased self-reports of negative emotions such as stress, and being overwhelmed and annoyed. Their findings imply that in a professional context, reducing interruptions and deferring notifications may work, however, for a personal context, strategies around communicating (un)availability and managing expectations appear more suited. Based, on these and similar studies, it is clear that a fine balance must be found that will allow for push notifications to encourage and motivate users to become more active and healthy but not frustrate, depress or annoy them.

Although there has been much research focused on exploring the negative effects of push notifications, there has been little work exploring how to utilize the advantages of push notifications for fitness and physical health.

2.5 Encouraging Healthy Habits

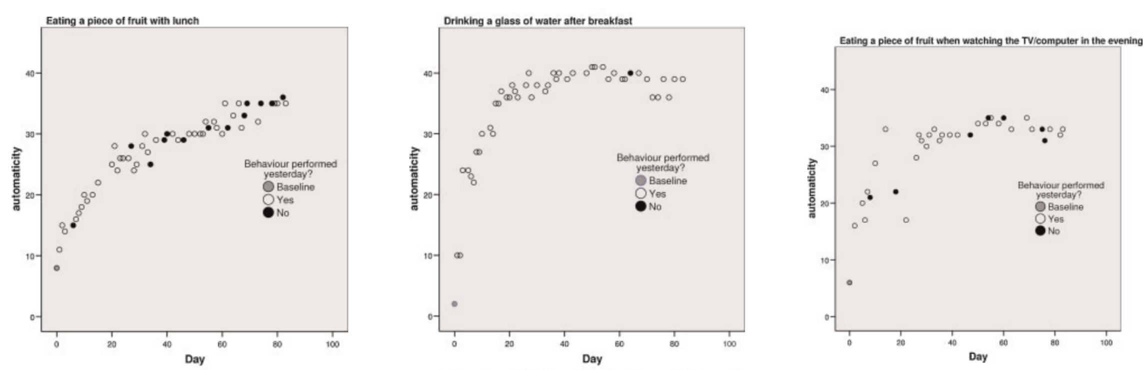
The World Health Organisation (2020) has identified "lack of physical activity" as one of the four key lifestyle behaviours that negatively impact health [30]. Previous studies have shown a nonlinear relationship between routine physical activities and reduction in the risks for various medical conditions, especially chronic conditions such as type II diabetes, and cardiovascular disease. The greatest relative benefits are seen when an individual changes from an inactive state to any level of physical activity [31].

Although most of the studies regarding physical activities are focused on the physical benefits of exercise, there are also mental benefits. Previous studies have confirmed the positive effects of physical activity participation on cognition, including the treatment and prevention of dementia. In addition, long-term participation in physical activities can reduce the risk of future depressive illnesses [32]. It has been shown that either a moderate or a high-intensity activity, which is done at least once per week, results in a significant reduction in the possibility of developing future depressive illnesses [32].

Although doing exercises and being physically active even in short periods of time can show short-term results such as temporary mood enhancement, long-term results require continuous and regular execution of fitness routines. In this section, in order to better understand how push notifications can encourage physical activity, we will first look at how healthy habits are formed.

2.5.1 Formation of Habits

In psychology, "habits" are defined as actions that are automatically triggered in response to contextual cues [6], for example, looking at your phone (action) after waking up (contextual cue). A previous study [7] has shown that with increasing repetition, automaticity steadily increases until it plateaus at approximately 66 days (Figure 6). Automaticity strength peaks faster for simpler tasks (e.g. standing up after hours of sitting) than complex routines (e.g. doing 10 lunges) [6]. In addition, smaller tasks have a higher chance of success and can result in increased self-confidence, thereby encouraging individuals to work towards other goals. Habit formation consists of different phases. The initiation phase requires the individual to have sufficient motivation to attempt a new habit-formation [6]. Individuals must choose an appropriate "context" for triggering the "action". For instance, going for a walk after having dinner. Self-chosen habits help individuals to remain determined during the learning phase of habit formation. Variation may also help to stay interested during this phase, however, it is incompatible with the development of automaticity. In the stability phase, the habit has formed, so that it is triggered automatically and it persists over time with minimal effort [6].



(a) (b) (c)

Figure 6: Examples of increases in automaticity score during the experiment conducted in [7]. With the same repetition count, simpler tasks reach a higher automaticity score.

2.5.2 Gamification for Habit Formation

In order to encourage users to be more committed to physical activities and continue working with a fitness app, we need to find out which elements can affect users' engagement with an application and help form healthy habits. Gamification is known as one of the successful ways of transforming an uninspiring task into one that engages users and actively encourages them to complete the needed task [33]. This characteristic of gamification can be used in mobile applications to boost user engagement. Gamification is defined as using game elements and game principles in a non-game context. Basically, by making an activity more like a game, individuals will be more motivated to do it. Some of the well-known game elements are rewards/scoring, competition, collaboration, avatars, and levels.

Different categories of fitness and health mobile applications that use gamification were defined by Wylie *et al.* [33]. The first group of apps focuses strictly on health. These apps provide a goal for the user and encourage them towards their goal (e.g. Jane McGonigal's "SuperBetter") [33]. Another group of applications works with an activity tracking device such as fitness bracelets or other wearable sensors (e.g. "Nike+", "Fitbit") [33]. Other applications are designed for a specific group of users, for example, mobile applications for people with Multiple Sclerosis [34] or for users who are going through a stroke rehabilitation process [33].

One of the most popular apps that use gamification for building habits is *Habitica* (Figure 7). In *Habitica* the user is able to make a list of habits they wish to build, a list of dailies that they need to do with repetition, and a list of to-dos which are one-time tasks. If the user succeeds in completing any of the tasks, they will be rewarded with in-app coins which later can be used to buy in-app items e.g. customs for the avatar. On the contrary, the user will lose health by doing negative habits. In addition to reward and avatar elements of a game, *Habitica* utilized collaboration and competition elements as well. This means users can make groups and complete tasks with their friends.

In another work [36], the authors inspected the effects of gamification on forming studying habits. For this goal, they developed a browser-based study system that allows users to review slides and take notes, answer questions in groups or individually, set goals, and track their progress. Users are able to set reminders in the system as well. The results of their study showed that participants believe that their system

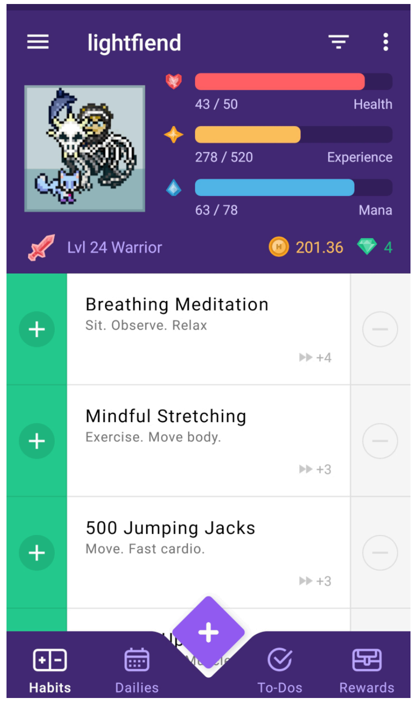


Figure 7: Screen shot of *Habitica* app from [35].

provides an interesting way of studying. However, after the user experiment, none of the participants continued using the system. This could be due to the fact that the time of the study was fairly short (30 minutes) which is in contrast to the nature of forming habits.

Similar to push notifications, gamification can be used to motivate users to adhere to fitness and health regimes in order to overtime develop healthy habits. Gamified wearables and their mHealth applications which have a successful design, have shown to increases users' engagement [37] and form a habit in the long term. In addition, different game mechanics can satisfy different motivational needs. For example, the use of positive feedback, progressive information, points, levels, and leaderboards can satisfy competence needs while the use of groups, messages, connection to social networks, and chat can satisfy relationship needs [38]. In Chapter 4, we describe our custom-developed app that uses both context-aware push notifications to keep users motivated and committed to doing regular workouts and correspondingly eventually build a habit of regular physical activity.

Chapter 3

Cueing and Feedback

To support effective physiotherapy and rehabilitation exercises both cueing and feedback from a professional are used to guide a person to perform a specific activity correctly [39]. Whereas, cueing is defined as using external temporal (related to time) or spatial (related to space) stimuli to facilitate movement *initiation and continuation* [40], feedback is defined as the information that is given based on a person's performance*during or after* an action, typically with the intention of improvement or motivation (Figure 8). In Figure 8, the difference in timing between cueing and feedback is shown for a specific study by Ede *et al.* [41] that investigated the effect of attentional cues on accuracy and reaction time.

Cueing can be used to gain attention, break patterns and improve learning retention. There are different cueing modalities that can be used, for example, visual, auditory, or somatosensory (e.g. haptic). In general, visual cueing provides more useful information; however, auditory information is processed faster [42]. Further, in movements where extra mobility is required, directing attention to visual cues might negatively affect a physiotherapy process. In these cases auditory or somatosensory cues are preferable.

Feedback can be either negative (e.g. a comment from a personal trainer if you crash the weights in the gym) or positive (e.g. praise from a personal trainer or a thumbs up) which can impact a person differently depending on the context [43]. Receiving personalized feedback can help users to feel motivated and improve their movements of exercises. However, the timing of the feedback can impact its effectiveness. Real-time feedback can inform individuals about errors in performing exercises

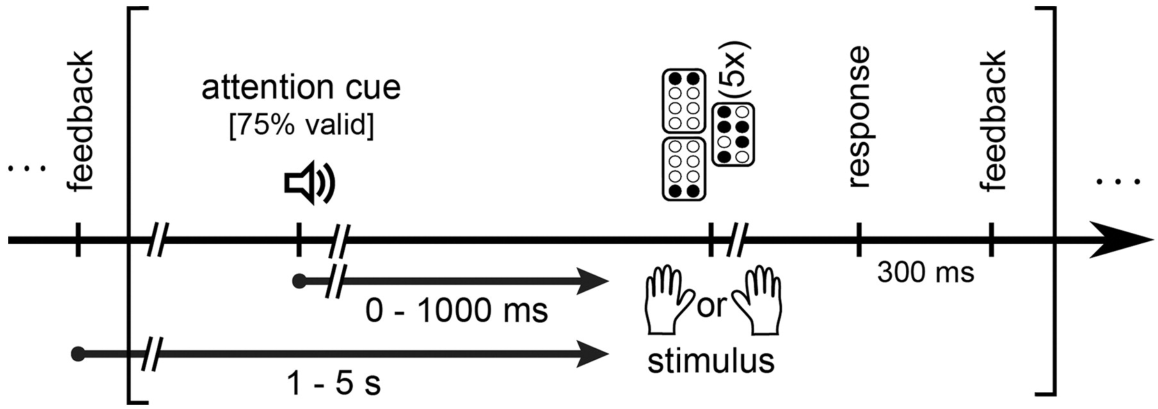


Figure 8: Timing for cueing and feedback: in a study by Ede *et al.* [41] investigating the effect of attentional cues on accuracy and reaction time, the authors used an auditory cue to inform users which hand they should expect a tactile cue on. After presenting the tactile cue, the user had to discriminate the approximate location of the cue by pressing a specific button. The user then received feedback based on their response.

and routines sooner, which allows for faster correction of the exercise. In physiotherapy, for example, this can result in quicker recovery and less injury for a person. One downside of real-time feedback is the need for constant supervision. The emergence of computer-vision and wearable sensors is beginning to enable automated feedback without the need for constant human supervision.

In this chapter, we discuss cueing and feedback solutions in the context of physiotherapy and rehabilitation. Specifically, we focus on evaluating multimodal feedback or cueing solutions using wearable sensors.

3.1 Wearable Sensors

Wearable sensors are devices that can be embedded into clothing (e.g. a smart bra) or worn as accessories (e.g. a smartwatch). These sensors capture data and send it to a server via the Internet or Bluetooth. They can measure different properties such as heart rate, position, acceleration, and temperature. Since sensors can work as portable and low-cost solutions, many applications have been found for wearable technology in different fields such as medicine, and entertainment. Wearable technology can be categorized into two main groups: (1) those operating independently e.g.

wrist-worn trackers, and (2) those that capture specific actions or execute a measurement and offload this data to an independent device for analysis e.g. wearable heart rate monitors [44].

Wearable sensors are becoming more and more frequently used in fitness and rehabilitation. According to a survey conducted in 2019, about one in five Americans, have stated that they regularly use or wear a smartwatch or fitness tracker [45]. Another popular wearable technology is posture enhancers. These sensors, which are placed on one's shirt or body, can be calibrated based on an individual's posture. Consequently, it can vibrate whenever the user is slouching and remind them to sit or stand upright. In general, wearable devices are a growing industry. Sales revenue from wearable devices is projected to grow from around 16 billion U.S. Dollars in 2016 to around 73 billion U.S. dollars by 2022 [46]. In addition to the fitness applications of wearable technologies, there have been many works conducted regarding the use of wearable sensors for therapeutic purposes. In the following section, we describe a number of research papers that explored the use of wearable sensors in the specific context of physiotherapy and rehabilitation.

3.1.1 Wearables in Physiotherapy and Exercise

Delrobae *et al.* [1] used wearable sensors to track tremor, which is one of the primary physical symptoms of Parkinson Disease (PD). They used an Inertial Measurement Unit (IMU) motion capture system to capture full-body tremor and distinguish healthy individuals from tremor-dominant PD patients (i.e. PD participant with a total Unified Parkinson's Disease Rating Scale (UPDRS) score higher than 2 while sitting at rest and being off of PD medication) as well as from non-tremor-dominant PD patients. The system includes 17 embedded IMUs, which measured linear accelerations, angular velocities, and magnetic forces in 3 axes (Figure 9). The authors used the IMU system to collect data from the user while they performed a predefined set of standardized tasks. Based on the collected data, a real-time 3D animation was generated along with a full-body tremor severity score. They found that the generated full-body tremor severity score correlated well with UPDRS. This finding denotes the feasibility of using portable wearable motion capture systems for automatically detecting and reporting the severity of full-body PD tremor.

Another study [47] demonstrated the use of wearable sensors in gait modification

Figure 9: A demonstration of the wearable motion capture system from the work of Delrobae *et al.* [1] for assessing tremor.

for people with knee osteoarthritis (KO) disability. The authors examined which type of real-time feedback (verbal or sensor vibration feedback) is more effective in improving gait. The sensor consisted of one control box which was placed on top of the user's sneakers, one force sensor under the sneakers, and one pager motor which was placed inside the shoe (where its vibration could be detected by the user's foot). The authors found that real-time active feedback produced a larger, statistically significant reduction in the first peak of the knee abduction movement compared with the verbal instructions. Thus they concluded, that haptic feedback is more effective than verbal instructions.

Doyle *et al.* [48] investigated if therapeutic exergaming (i.e. the combination of exercising and gaming or gamified exercises) can improve patient's accuracy in performing exercises and their adherence to a recovery program. The authors conducted a preliminary study with 3 groups: (1) a control group that did not use any type of feedback, (2) a video group that had limited feedback in the form of a demonstration video prior to performing the exercises, and (3) an exergame group which was provided with real-time visual feedback in the form of an exergame. In the exergame, the user has to maintain a spaceship on a predefined path with their movements. If they fail to move along the path or do not maintain a regular pace in their movements, they lose points which prompts them to correct their movements (Figure 10). The authors used an iPhone strapped to the user as a sensor to capture motion data. Overall in the user study, participants in the exergame environment showed more accuracy over no feedback and limited video feedback environments. Another interesting finding of this study was that under limited video feedback participants performed less accurately compared to a no-feedback environment. This might be due to the fact that participants were more focused on remembering the instructional video rather than their performance.

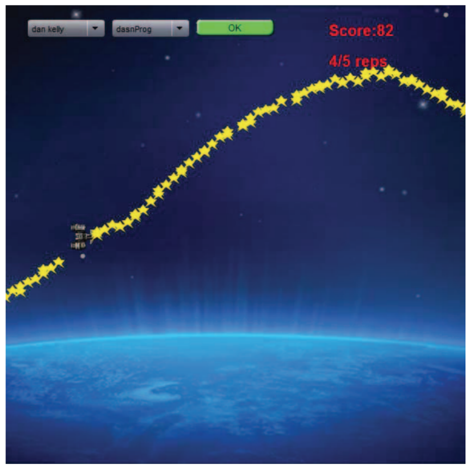


Figure 10: One of the exergames from the work of Doyle *et al.* [48]. In this game, the user has to maintain a spaceship on a specified path using body movement.

Papakostas *et al.* proposed a method based on electromyography (EMG) objective measurements for detecting physical fatigue, which is a very common symptom for different medical conditions [49]. Based on their findings and machine learning modeling, the authors plan to design customized adaptive rehabilitation scenarios that refine their instruction based on the user's physical and mental condition. In their experiment, participants had to perform shoulder flexion, shoulder abduction, and elbow extension exercises. During the exercises, participants used the robotic Barrett WAM arm, which provided a resisting force to the subject. In addition, the authors used Delsys, a non-intrusive EMG sensor to capture EMG data from the muscles which were responsible for each exercise (Figure 11).

3.2 Feedback and Cueing

In the following sections, we explore different feedback and cueing modalities in the context of physiotherapy. It should be noted that some researchers use these terms interchangeably and in the related works, we choose the term that was used in the

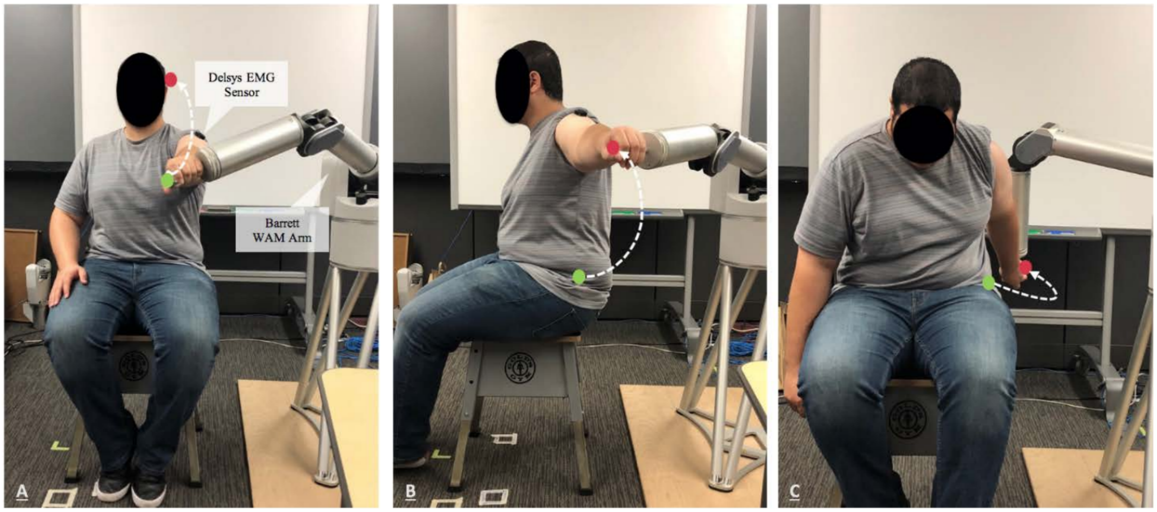


Figure 11: The experiment setup for shoulder flexion, shoulder abduction, and elbow extension from the work of Papakostas *et al.* [49]. The green circles and the red circles indicate the start positions and the end positions respectively.

paper being described.

3.2.1 Modalities

Any type of cueing or feedback can direct a user's attention to the task taking place. Feedback and cueing can be categorized by type into three main categories: visual, auditory, and somatosensory (see Figure 12).

In the context of health, the cueing and feedback that is normally given by a professional is visual (e.g. demonstrating the proper way to make a move), auditory (e.g. giving verbal instruction), or somatosensory (e.g. moving a person's limb into the right position or applying pressure to a specific area of the body) [51]. However, cueing and feedback can also be given, rather than by a person, by using a device such as a monitor, speakers and/or wearable sensors.

In terms of cueing specifically, visual cueing has been defined as the addition of non-content information to visual representations and can have various formats including graphics (e.g. arrows, coloring, flashing, etc.), on-screen narrations and/or texts [52]. The most studied type of auditory cueing is rhythmic auditory cueing [53] such as the use of an underlying beat in music [54]. Combining different types of feedback or cueing can convey a better understanding of a task since humans naturally interact with multiple modalities. However, if not designed carefully these cues can

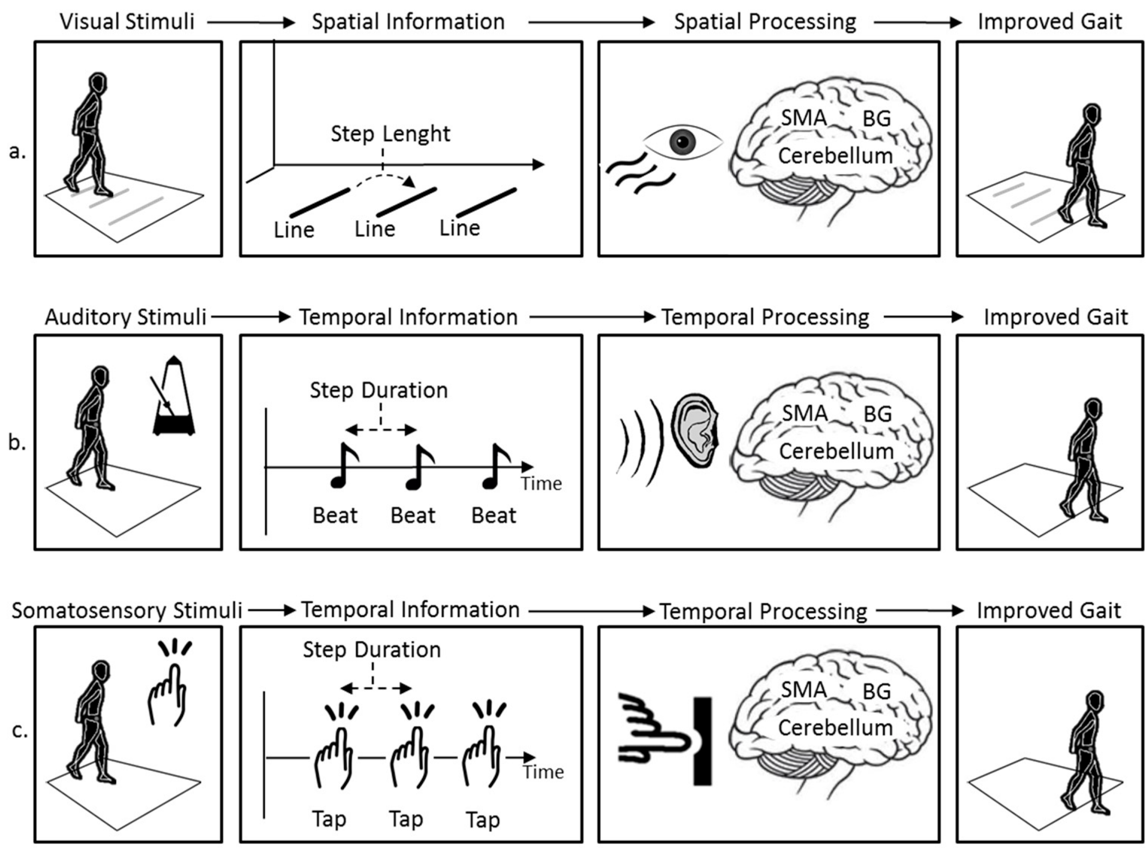


Figure 12: An example of three types of cueing used for improving freezing of gait in people with Parkinson's Disease. (a) Parallel lines drawn on the ground with the same distance are a visual cue that specifies step length. (b) A fixed beat is used as an auditory cue to specify step duration. (c) Tapping a patient's shoulder in a fixed rhythm used as a haptic cueing). [50].

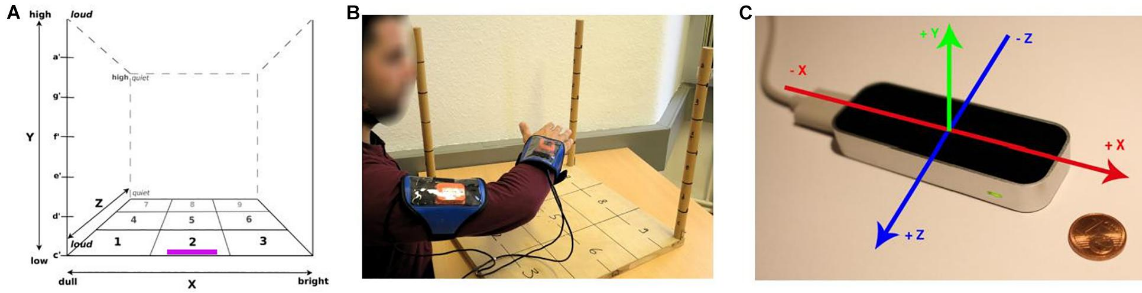


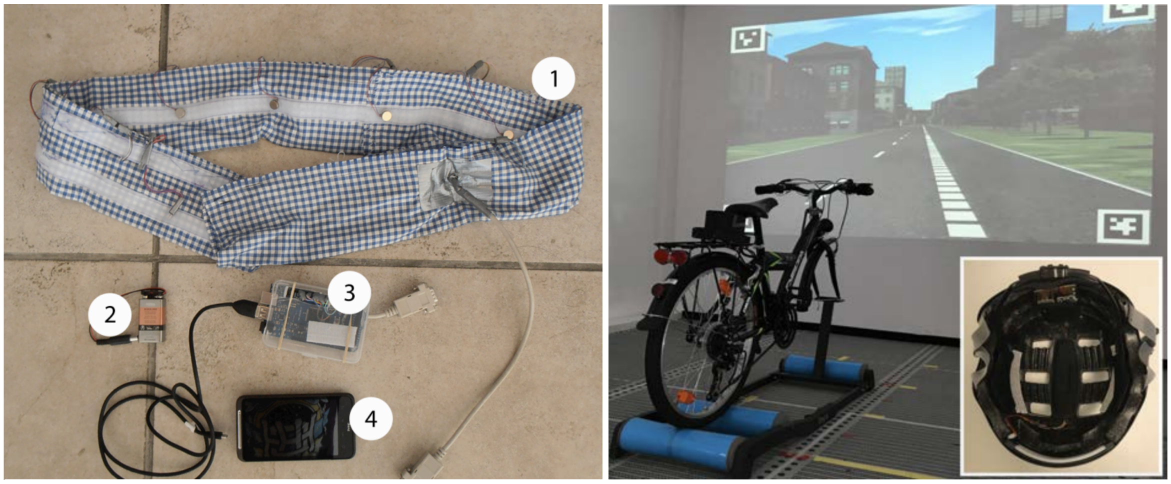
Figure 13: Figure from a study where sonification (i.e., changes in musical pitch) was used to look at its impact on post-stroke arm rehabilitation[55]. (a) three-dimensional space with axis labels describing qualitative sound changes when the hand was moved. The placement of the Leap Motion sensor is marked in purple. (b) Two sensors were attached to the individual's affected arm. (c) A Leap Motion was used to measure the kinematics of movements and movement smoothness.

overload users with too much information and confuse rather than help [51].

3.2.2 Feedback and Cueing Modality in Physiotherapy and Excercise

Nikmaram *et al.* [55] did a study on post-stroke rehabilitation with music therapy. They used sonification (i.e., changes in musical pitch) of each individual's affected hand movements to play simple familiar tunes. They gathered data using two sensors attached to the wrist and arm of a patient (Figure 13). Their results did not show any effect of musical sonification on training, however, they did find a small effect of sonification on movement smoothness.

Haptic cueing or feedback, which is typically represented as vibration, can show its superiority over visual and audio cueing and feedback in contexts where the focus should be directed towards other information in the environment, e.g. navigation for cyclists. Steltenpohl *et al.* [56] investigated the potential of tactile cues for giving navigational information to cyclists with the use of a customized belt. Their system is capable of giving information about directions (by vibrating in the direction of the next part of the route), endpoint (vibrating continuously) and waypoints (interruption in endpoint's vibration) on a route. Their system also consisted of a visual navigation part to be compared with the Vibrobelt (Figure 14a). The results of their study showed that although the system resulted in cyclists doing more wrong turns, they had fewer near-accidents.



(a) (b)

Figure 14: (a) Hardware setup of Vibrobelt from [56]: (1) The actual belt with eight vibrotactiles, (2) a power source, (3) an Arduino Mega ADK, (4) and an Android phone; (b) Bicycle simulator from [57]: bicycle on a stationary platform fitted with unimodal and multimodal feedback with a street view simulation projected on the wall.

In a similar work by Matviienko *et al.* [57], the authors explored which type of feedback can be more effective in increasing child cyclists' awareness in critical situations. The authors used a bicycle simulator for their study which was fitted with an LED display and small audio speakers on the handlebar and vibration motors in the saddle and the grips. They found that perceiving visual cues was more time-consuming than auditory or vibrotactile cues. Although unimodal signals were more suitable for encoding directional cues, the use of all modalities simultaneously was found more helpful for priming stop actions.

Feedback and Cueing Modality in Parkinson's Disease

Parkinson's disease (PD) is a brain disorder that leads to shaking, stiffness, and difficulty with walking, balance, and coordination [58]. It is one of the most common disorders, in which symptoms appear gradually with ageing. Since much research on using cueing and feedback modalities, has been conducted regarding alleviating PD symptoms, we will exclusively introduce some of these works in this section.

In a study by Gallagher *et al.* [59], the authors investigated if auditory cueing, visual cueing, feedback, and directed attention have any influence on cycling in healthy adults and those with PD. The user study setup consisted of a stationary bicycle, a cadence sensor attached to the crank of the bike pedal, and a projector to project the virtual environment onto a flat wall. The virtual environment consists of an avatar riding a bicycle in the first-person view on a straight road. Audio cueing was provided by a pair of desktop speakers connected to an iPhone metronome application which was set at a rate 20% higher than the baseline pedaling rate. Visual cueing was in the form of central road markers and visual feedback was generated in the form of the white central road markers, which changed to purple when participants cycled at a predetermined rate. In the directed attention condition, both auditory and visual cues were presented simultaneously; however, participants were instructed to direct their attention to only one of them. The results of the study showed that only audio cueing and directed attention helps healthy individuals to increase their cycling speed. However, for people with PD, all 4 conditions affected pedaling rate positively.

Edd *et al.* [2] used visual cues for developing a system to help in gait rehabilitation. Their system consisted of an optoelectronic motion capture system for collecting gait data and in-ground force plates. For evaluating the system, after collecting gait data of healthy participants' normal gait without visual cues, the participants were familiarized with visual cues and they were given time to practice with the system. In addition to a visual cue showing the average normal foot placement, the participants were shown their own achieved foot placements overlaid onto the average to provide accuracy feedback as shown in Figure15. The authors found that floor-projected visual cues can alter healthy individuals' gait biomechanics but that these differences are clinically negligible.

In a study conducted by Lim *et al.* [60], the authors investigated the effects of a home-cueing training program on the level of physical activity especially gait-related activities (e.g. walking speed, step length) in Parkinson's Disease (PD) patients. In a three-week user study participants used a prototype cueing device to receive training in their home environment. This cueing device provided guidance with 3 rhythmical modalities: auditory (a beep), visual (a flashing light), and haptic (a miniature vibrating cylinder on the wrist). The activity monitor that was used in the experiment consisted of 5 accelerometers connected to a portable data recorder worn on a belt around a participant's waist. The results of the study showed that most

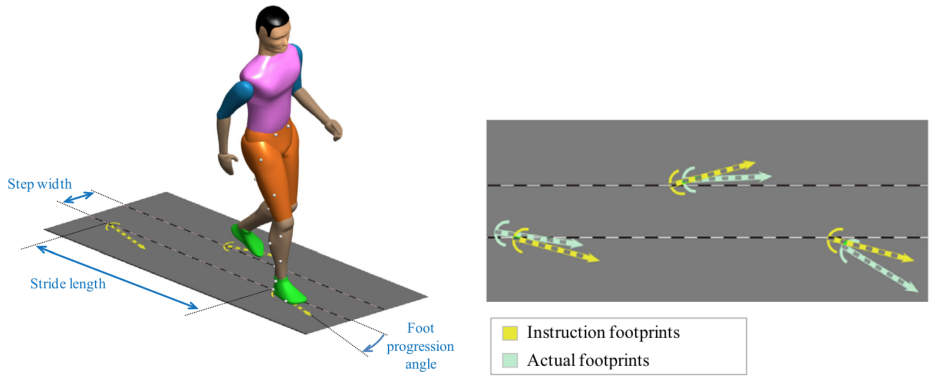
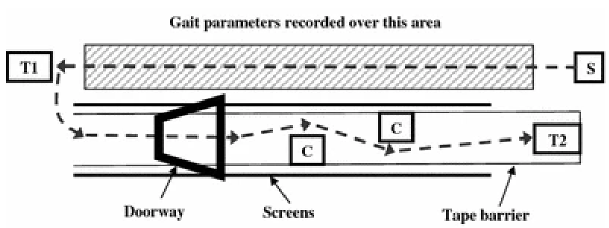


Figure 15: Experiment setup of the system in [2] taken from [3]: (a) Illustration of a patient walking on the provided instruction footprints as visual cues. (b) Example of a possibility offered by the system to display the actual footprints of a subject superposed onto the instructional footprints.

of the participants chose auditory cueing as their preferred cueing modality, whereas the rest favoured haptic cueing. Besides, cueing therapy showed a notable positive effect on dynamic activity (i.e. an increased amount of walking activity of 35 minutes per day).

In another study, Ford *et al.* [54] investigated the effects of auditory cues on gait training in individuals with Parkinson's Disease. In their work, the authors focused on three main characteristics of walking: walking speed, stride length, and cadence with the goal of maximizing stride length while walking at the fastest cadence possible. They performed a user study in which participants trained 30 minutes a session, 3 sessions a week for 8 weeks while wearing a heart rate monitor, an iPod on their arms and headphones for listening. Auditory cues used in training sessions were based on each individual's comfortable cadence. Each participant was instructed to "step to the beat of the music.". Their findings showed a significant increase in stride length and cadence in participants with PD after training with progressively increasing external auditory cues.

In a study by Griffin *et al.* [61], the authors investigated the effect of real and virtual visual cues on walking in Parkinson's disease patients. Their user study with 26 PD patients was conducted on different conditions: medications on and off and different intervention conditions (no guidance, cueing with virtual reality glasses (VRG rhythmic, visual flow and static placebo cues), transverse lines (TL) on the floor). Their findings showed that cueing intervention affected task completion time only when subjects off medication. In addition, although the VRG provides more flexibility rather than TL, using VRG as a means of cueing did not result in much improvement in participants' gait. While the placebo condition provided no improvement in any walking parameters, the visual flow condition slightly reduced the task completion time. TL conditions improved participants' gait with reduced cadence, increased stride length and reduced freeze of gate (FoG) frequency. Finally, rhythmic cueing which was provided as rhythmic full-screen red/black flashing stimulus impaired overall walking (Figure 16).



(a)

(b)

Figure 16: (a) Walking task schematic with walking path indicated by a dashed line. During the experiment, subjects rose from a chair (S) and walked 11 meters to touch a target (T1). Then the patient turned 90 degrees left; before walking into a narrow section made by fabric-tape pedestrian barriers and surrounded by dark partition screens. Patients then walked through a freestanding doorway and a 'chicane' made by 2 chairs, before touching a second target (T2). The patient then turned 180 to repeat the course in reverse. The task ended when the patient sat down in the starting chair; (b) Virtual reality glasses and processing unit used in this study [61]

AR and VR in Physiotherapy

In recent studies, the use of Augmented Reality (AR) and Virtual Reality (VR) either on desktop, mobile devices, or head-mounted displays (HMD) have been very popular as visual feedback. VR replaces the actual reality with a computer-generated 3D world where the user can interact with and explore, whereas in AR the real world is not replaced but augmented with virtual objects.

Garcia *et al.* [62] developed a mobile application using AR and gamification to help individuals with ankle sprain injuries rehabilitate (Figure 17). In a similar work, Alamri *et al.* [63] developed a set of serious games for exercising for post-stroke motor recovery of hands and arms using AR. The system also provided tools for the therapist to monitor patients' progress and change patients' treatment plans accordingly. Shin *et al.* [64] developed a task-specific interactive game using VR for post-stroke rehabilitation of upper body parts. The system does not use any controllers or attachments which makes it ideal for patients who have not regained sufficient hand power to use a game controller to interact with the system; however, it used an OpneNI™-compliant depth sensor and three monitors which makes it inaccessible in some contexts (e.g. home rehabilitation exercising). All of these systems can constantly give feedback to patients to help them stay interested in their rehabilitation process without the need for continuous supervision.

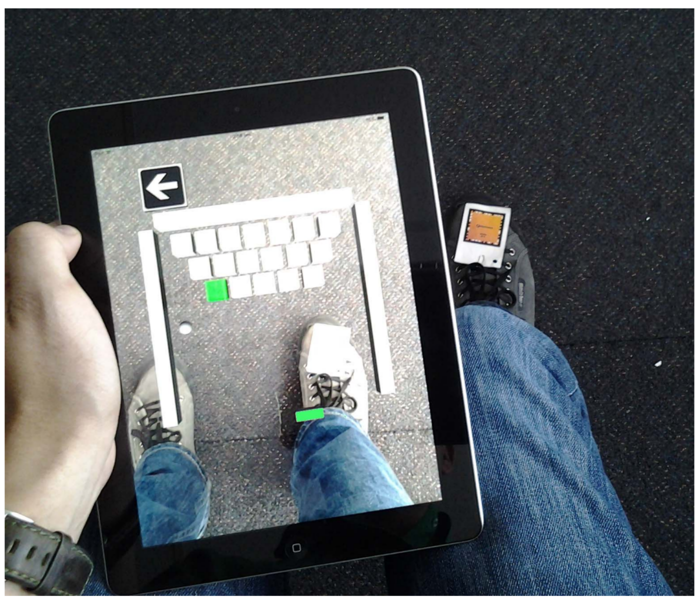


Figure 17: A demonstration of Mobile RehApp application from the work of Garcia *et al.* [62] for ankle sprain rehabilitation.

In another work, Sousa *et al.* [51] presented an intelligent interface using projection-based augmented reality to help individuals perform upper-body rehabilitation exercises without constant supervision. The system provides real-time visual feedback projected both on the floor area inside the field-of-view and on the arm of the user. Based on the region of the arm, the visual feedback on the floor changes. In addition, it provides audio feedback for important notifications such as body stance errors. The authors also used audio and visual cues for guidance and for informing participants about the start and end of the exercises and transitions between moves (Figure 18).

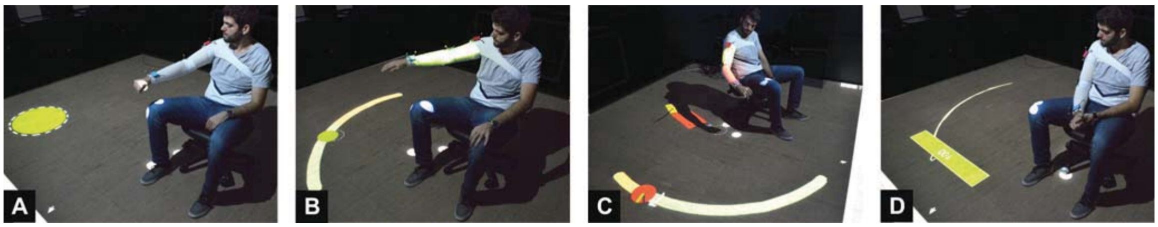


Figure 18: A demonstration of SleeveAR from the work of Sousa *et al.* [51] for upper-body rehabilitation.

In this chapter we provided background on the use of wearables, cueing and feedback in the specific context of exercise, physiotherapy and rehabilitation. In Chapter 3, we explore the use of gamification and cueing in a specific study on wrist physiotherapy exercises.

Chapter 4

Impact of Push Notifications on Fitness

A short version of this chapter was presented at the 22nd Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI'20):

> Haghbin N., Kersten-Oertel, M. On the Impact of Context-Aware Notifications on Exercising. *In Proceedings of the 22nd ACM International Conference on Human-Computer Interaction With Mobile Devices and Services (MobileHCI '20)*, October 5–8, 2020, Oldenburg, Germany.

4.1 Introduction

Mobile push notifications are a common means to send messages from a mobile application to the user's device. These messages can have different purposes and may be received at any time of the day in different modalities on a smart device. In this chapter, we describe an experiment that was conducted for exploring the effect of push notifications in motivating users to be active. First, we surveyed 105 diverse users on their use of push notifications. Based on the results of our survey, we used different types of push notifications to explore their impact in the context of exercise. Specifically, we developed *5 Mins*, a custom iOS workout mobile application with the ability to send daily reminder notifications based on a user's location, the current level of activity and at a pre-defined time. A small preliminary user study showed that even though reminder notifications can help to direct the user's attention to doing a workout, the user does not necessarily follow through with the workout.

4.2 User Survey

To get a sense of user preference regarding push notifications, we developed a questionnaire probing people's use and perceptions of push notifications. The questionnaire was created using Google Forms [1] and was sent out using social media and email. The overall goal of the questionnaire was to answer the following research questions: *Which modality (visual, aural, haptic) is the most appropriate for a given notification in a given context?* and *When is the ideal time and where is the ideal device to receive a specific type of notification?* The questionnaire consisted of approximately 40 questions targeting 3 different contexts: work-related push notifications (e.g. calendar reminders), (2) home-related push notifications (e.g. smart alarm system notifications), and (3) reminder notifications in the specific context of fitness and healthcare purposes. For each scenario the questions targeted three main issues: (1) *what device* notifications should be received on (e.g. smartphone, smart speaker, watch), (2) *which modality* should notifications have (e.g. text, voice, vibration, combination), *when* is the ideal time to receive a notification?

4.3 Results: User Survey

We had 105 participants answer the survey (42.9% female, 56.2% male, aged 18 to more than 65 years old, mean=30.81 years). Since they were mostly from engineering and computer science (39%), and medical science and psychology (8%) backgrounds, their practical knowledge of technology were generally good (41.1%), and very good (34.7%). About half of the participants (48.6%) had an iOS mobile device, and 51.4% were Android users. Just over a quarter (29 participants) owned a smartwatch which was used for checking time (82.1%), heart rate monitoring (60.7%), activity monitoring (57.1%), push notifications (57.1%), call and text (53.6%), burnt calories (35.7%), GPS (25%), sleep monitoring (28.6%), ECG (3.6%), and finding their phone (3.6%).

[1] https://forms.gle/J1FuBcPqQGf8Pwbj8

Regarding push notifications, the majority of participants (65.7%) tend to customize the notifications that they want to receive from apps and disable those that they don't. About one-fifth of participants (21%) do not customize push notifications but rather use the default settings. The rest of the participants either disable all notifications (8.6%) or keep them enabled but ignore them (4.8%). Since in previous works it has been shown that non-tech-savvy users usually do not configure their notification settings [65], the large number of participants who customized the notifications that they wanted to receive might be a result of the fact that the majority of our participants were from a tech-related background. Based on the survey, the three most popular types of notifications are reminders (78.1%), social media notifications (55.2%), and updates (43.8%).

Regarding trust management, data privacy was found to be very important (52.4%) or important (32.4%) to the participants. This may be a higher percentage than the general population as the majority of our participants were found to be tech-savvy. The participants however, were still willing to share data concerning: age (60%), gender (56.2%), pedometer (50.5%), location (49.5%), heart rate (48.6%), weight (46.7%), height (45.7%), accelerometer (45.4%), barometer (42.9%), ECG (34.3%), contacts (12.4%), microphone (9.5%), storage (8.6%), and camera (8.6%) to have better tailored push notifications. Additionally, we found that 67.6% of the participants tend to change an application's default permissions for accessing data.

Although the questionnaire surveyed push notifications in three different contexts, we focus on the results of the fitness and health questions. However, the interested viewer is directed to the full results[2].

4.3.1 Push notifications for fitness and health

We found that 36.2% of our participants currently use push notifications for health and fitness tracking. Of them, 50% use push notifications to remind them to exercise, 27% use push notifications to remind them to have mindful moments, 36.8% use push notifications to remind them to stand up, and 55.3% use push notifications as reminders to move (Figure 19).

The majority of participants, prefer to receive notifications related to fitness either on their mobile device (60.5%) or smartwatch (60.5%). This matches former study

[2] http://bit.ly/2tdooH0

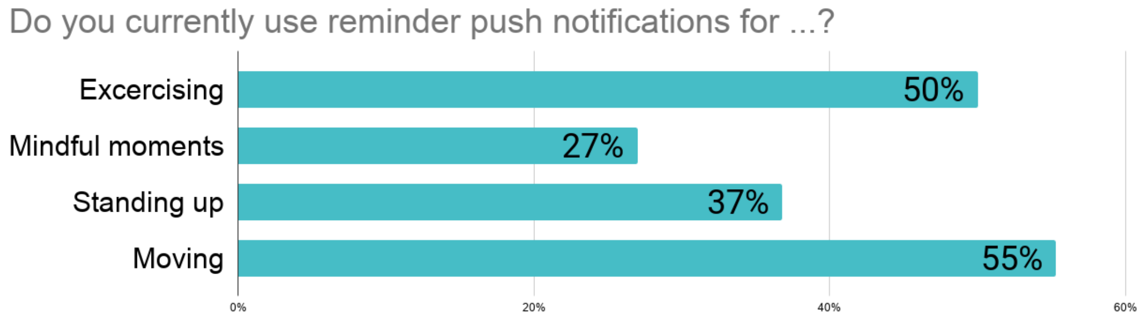


Figure 19: User's preference for reminder push notifications related to fitness and well-being out of 37 responses.

results on multi-device notifications. Since smartphones are typically turned on and reachable most of the time, it's usually the primary notification device for people [65]. This reasoning applies to smartwatches as well. In contrast, a very small number of participants favour push notifications on their tablet (2.6%) or smart speaker (2.6%). This can be because these devices are not easy to carry around and are less reachable for people. Regarding the modality of notification (text, voice, vibration and voice, vibration and text, voice and text, tone and text) the top three are text (60.5%), vibration and text (60.5%), and tone and text (50%). The least popular ones were found to be vibration and voice (47.3% did not like this modality), voice (44.7% did not like this modality), and text and voice (39.4% did not like this modality). Similar results were found for mindfulness notifications. We might be able to connect this to the fact that privacy was found to be very important (52.4%) or important (32.4%) to the participants and having voice notifications does not comply with private notifications since the content of the push notifications will be said out loud.

In terms of the quantity of push notifications, we found that 55.3% of the participants prefer to receive push notifications concerning fitness once a day, 10.5% preferred once a week, 7.9% preferred twice a day, and 7.9% preferred more than twice a day (Figure 20). The ideal times to receive push notifications related to fitness and well being were: "When I have not been active enough" (63.2%), "In the morning before I start my day" (47.4%) and "In the evening if I have not been active enough" (34.2%), see Figure 21. On a scale of 1 to 5, (5 being most useful), most participants replied 4 to push notifications being useful in staying motivated.

Lastly, we found that the majority of participants (63.2%) prefer short notifications with only title and no details.

4.4 Preliminary User Study

To study mobile phone users' preferences for notifications, and the impact of these notifications on motivating users to exercise, we conducted a one-week small preliminary study with 5 participants. The study involved users downloading and using a custom-designed fitness application, which had custom-designed push notification reminders.

4.4.1 Participants

For the study, 5 participants (all male, age 18 to 34) were recruited who had iOS smartphones. Two participants had full-time jobs, two were students, and one was unemployed. The field of study/work for all participants was technology-related.

4.4.2 Pre-test Questionnaire

At first, a consent form was sent to all those who were interested in joining the study. Once those people had read the consent form and agreed to take part in the study, they were asked to complete the pre-test questionnaire. This questionnaire collected information such as demographic data, questions about the participant's preference

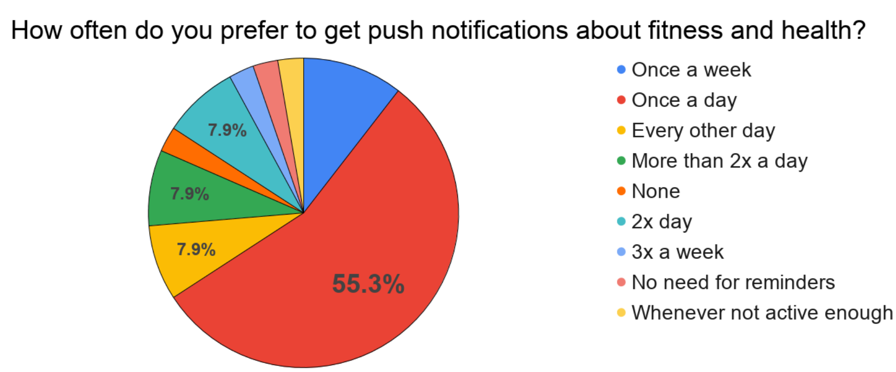


Figure 20: The ideal quantity to receive push notifications related to fitness and well-being.

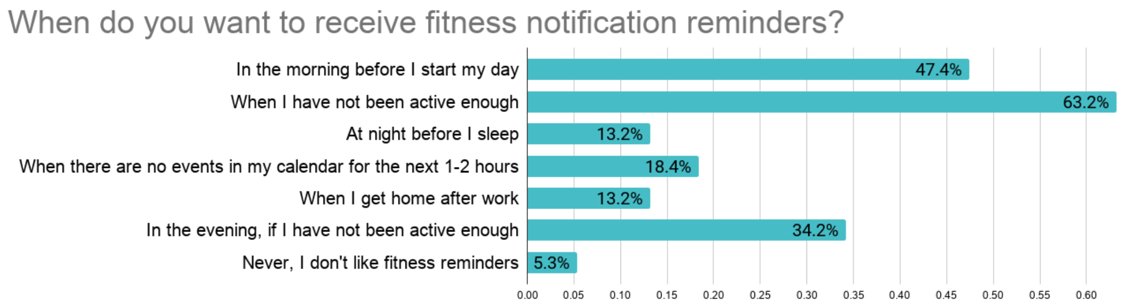


Figure 21: The ideal times to receive push notifications related to fitness and well-being.

of push notifications specifically in the context of fitness and health, as well as, their current use of fitness apps.

4.4.3 *5 Mins* Fitness App

The implemented workout application was built for iOS devices. The application consists of 4 sections for total body, upper body, lower body and abs workout (Figure 22). The app is made to look and feel similar to two of the most downloaded fitness apps available in the App Store: 7 Minute Workout: Fitness App (8.4k download and 4.7 stars) and Workout for Women (31k downloads and 4.7 starts). Users can customize each fitness routine and add or remove the workouts that they prefer. All of the workouts are inspired by DAREBEE workout routines, a free global fitness resource. A tutorial video for each workout is also provided.

The first time the user opens the app, they will be asked for the app's permissions to send notifications and tracking the user's location. After giving the authorization, it will set three types of default notifications, based on the results gathered from our survey. The first type is scheduled for a specific time that is set by the user. By default, this time is set to 8:00 A.M., which is compatible with the second most popular choice from the questionnaire: "In the morning, before I start my day". Further, if the user has not been active enough the day before, the content of these notifications will be more encouraging next day, e.g. "Today is a new day!".

The second type of notification is based on the user's location. We assume that users will use the app for working out mainly in locations that they do not have access to special equipment e.g. their home. Hence, for location-based notifications, the app

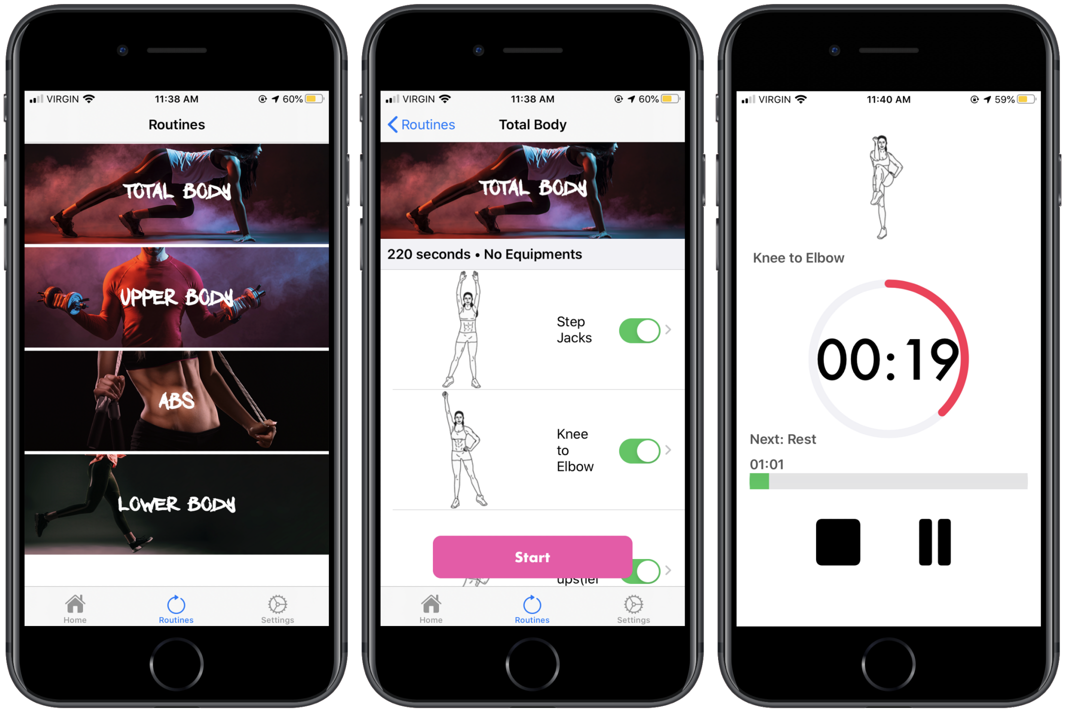


Figure 22: Screenshots of *5 Mins*

saves the location of the user each time that they start a workout routine from the app. Consequently, it is able to find the most frequently chosen location for using the app to workout and set a notification for that location. Furthermore, the user can modify the amount of time that is needed to pass after entering that location for the notification to be sent.

The third type of notifications is based on the user's activity. Based on the survey results (Figure 21), the most ideal time to receive a notification as a reminder for working out is "When I have not been active enough" and the third most ideal time is "In the evening if I have not been active enough". So the default time that we chose for this reminder, is 8:00 p.m. After tapping on this notification, the user will be sent to the activity history of the app. They will then be able to see their progress for that day and their total history over time and compare different sections with each other. This type of notification will be disabled if the user has done 2 minutes of each type of workout for that day.

According to our questionnaire results, the majority of people prefer notifications with only title and no details, thus we designed notifications that are clear, yet comprehensive. Example notifications are shown in Figure 23.

(a) (b)

Figure 23: Screenshot of different types of notifications on (a) a mobile device and (b) a smartwatch.

4.4.4 Post-study Process

The post-study process consisted of three parts: sending screenshots from the app, filling out an online questionnaire, and having an interview. Since most of the participants were not able to meet in person at the end of the study, we asked them to send screenshots of the app. These screenshots showed the exact time and date of the tapped notifications, the start and duration of the routines and the main page of the settings. In the post-study questionnaire and interview, we targeted participants' reaction to the push notifications and their perception of the push notifications. In addition, they were asked about any changes in their workout routines that might have resulted from the reminder notifications and any further suggestions for improving the usability of the app.

4.5 Results: Preliminary User Study

During the study period, a total of 5 participants had the app installed on their phone for a duration of one week. This section focuses on how the design approaches impacted users' experiences of using *5 Mins* to start working out and stay motivated to be active in their everyday life.

According to the pre-test questionnaire, 4 of the subjects customized their notifications and disabled the default ones. One of the users had them all enabled but their device is usually set to "do not disturb". Participants' preferences regarding push notifications were generally towards reminders (5 subjects), update notifications (3 subjects), social media notifications (2 subjects), and geolocation notifications (2 subjects). Their habits in terms of exercise varied from hardly ever (1 subject), 1-2 times a week (2 subjects), to 3-4 times a week (1 subject), and 5-6 times a week (1 subject). The majority of the participants (4 subjects) considered themselves as a person who is concerned about their health. However, several factors such as not having enough time (4 subjects), and forgetting to exercise (3 subjects) keep them from working out regularly. None of our participants were currently using reminder push notifications for exercising and 3 of them had never used them before. The rest of the participants stopped using push notifications since they were not motivated (1 subject), they do not exercise anymore (1 subject), reminders were not as useful as they thought (1 subject), and because of poor timing of the notifications (1 subject). Unlike the survey's result, the group of participants preferred to get fitness reminders once a week (4 subjects) with more details rather than just the title (4 subjects).

4.5.1 Reaction to Notifications

By default, if participants authorize the app to always track their location, they received more than 2 notifications per day. Two users did not authorize the app to track location and three users only allowed it while they were using the app. Based on this, the participants were prompted 70 times for the week of study to begin their fitness routine. However, only 7(10%) interactions resulted from the notifications, 6 of which were unintentional and did not result in starting a workout routine.

Based on the post-test questionnaire, the majority of participants (3 subjects) believe that the notifications were motivating. As one of the participants cited, "...It [reminder notifications] reminded me that I still need to do my workouts even in busy days". The least effective type of reminders were location-based reminders which none of the participants felt were very helpful. This might be due to the fact that participants did not give full location tracking permission to the app because all of them are very concerned (2 subjects), or somewhat concerned (2 subjects) about data privacy. Additionally, iOS users are encouraged to not allow the apps to track their location in the background and will be prompted to change the authorization if they do permit an app to always track their location.

In terms of the users' feelings after receiving a reminder at a time when they couldn't workout, 3 of them just ignored it without any negative feelings, 1 felt pressured and 3 were more motivated to do the workouts in the near future.

Regarding the content of the push notifications, users believed that having more dynamic messages could help to not overlook them as easily. Furthermore, 3 of the participants agreed on getting more information such as links to health-related articles or steps count might be more helpful. In addition, one of the participants suggested adding daily goals to the app and use the reminder to show their daily progress and give encouragement based on it.

4.5.2 Time Spent Working out

Based on the interviews, those who had a routine before using the app and did regular workouts (3 subjects), continued to do the same during the study. However, only one of them changed their routine to comply with workouts in the app. We also found that 4 of the participants believed that having the feature to add your own exercise can be a motivating factor. As one person mentioned, "Letting a user add their own exercises could help them tailor it to their specific use case."

4.6 Discussion & Conclusion

The results of our work suggest that push notifications in any context require consideration of that context's special set of characteristics in order not to neither create negative effects nor be ignored. Regarding the specific context of health and fitness, people tend to favour being reminded to be more active; however, these reminders need to have dynamic content and be received at times that the user has not been active enough. In terms of privacy, in our participant population, which had a majority of technologically savvy participants, the respondents were more concerned with their privacy rather than interested in receiving location-based notifications. It will be interesting to see in future work if a similar trend exists in the general population.

In terms of limitations, our preliminary push notification fitness study had 5 male technology-friendly iOS users. The results may not generalize to other segments of the population. In particular, the findings may not apply to people who are less concerned with the data gathered from their phones, who use Android devices with LED notification modality, or who are not too occupied by their daily activities. Further, long-term results on the impact of notifications have not been collected. At the same time, our results begin to provide evidence that people do believe that push notifications that are received at the right time and on the appropriate device with proper modalities can motivate them to exercise, however, they might not show any success in a short period of time. Furthermore, our study underlines the importance of exploring the trade-offs between privacy and more tailored reminder messages. The next step of this work will be to do a more extensive and long-term study, to better understand the impact of reminder push notifications on motivation and specifically exercise routine completion.

4.7 Post-fix: Updated *5 mins* App

After the preliminary study, we applied several changes to the *5 mins* app based on user feedback. In addition to minor changes in the design of the app, more features were added including badges (gamification), importing daily activities into the app, and a walk-through of the app.

In the first version of the app, only the exercises available as part of the fitness routine in the app were added to the "activity history" for each day. The lack of ability to add other activities to the daily physical activity page of the app raised some complaints. Hence, the activity history part was changed to a diary tab that not only tracks the activity within the app but also allows users to add their own customized workouts (e.g. 30 mins of swimming). Furthermore, we added synching data from the phone such as step count, on the condition that the app was permitted to do so. Consequently, users have a more complete history of their daily physical activities. Moreover, more control regarding the duration of the routines and rest duration within the routines was given in the new version of *5 mins* (Figure 24).

The second feature that was added to the *5 mins* app is an achievements tab. As mentioned before, one of the popular techniques for making an application more

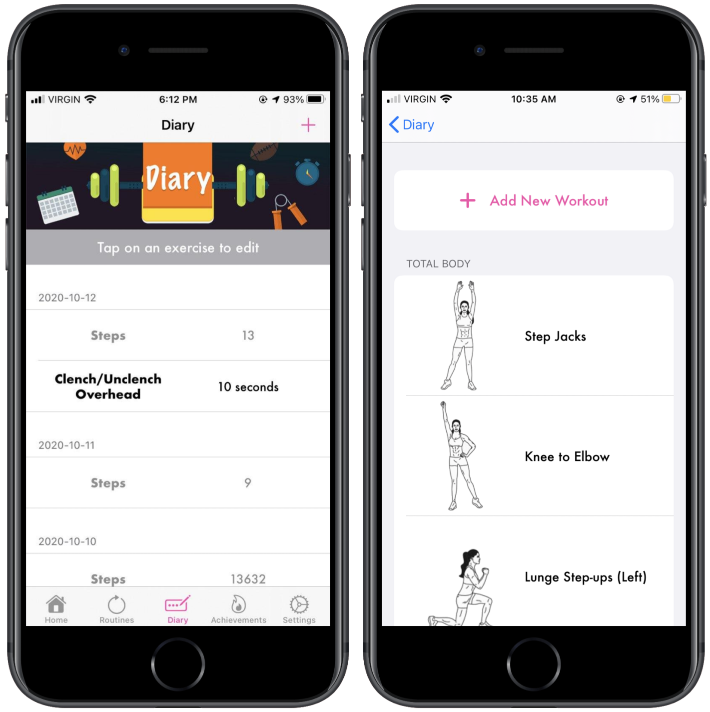
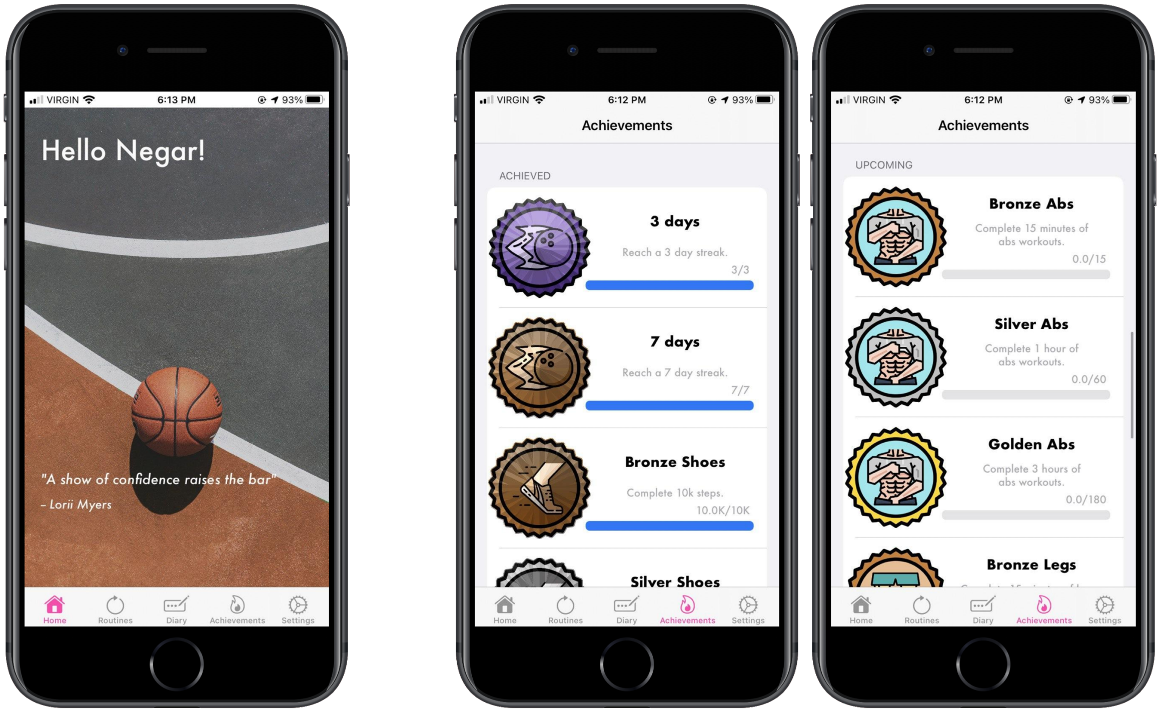


Figure 24: Screenshots of the Diary tab. Rows which are grayed out are synced automatically and cannot be edited.

engaging is the use of gamification. Recognizing different physical achievements in a workout app can keep users motivated regarding continuing to do exercises. Therefore, in the achievements part of the app, there are different award badges, ranging from completing a specific amount of time of different workout types to reaching a new level for step count. We hypothesize that this feature will motivate users to set achievable goals regarding physical activity and encourage them to work towards their goals (Figure 25b). Besides, to keep users motivated, the home page of the app was changed to a welcome page that greets the user and shows daily inspirational quotes (Figure 25a).

Finally, a walk-through of the main functionalities of the app was added and is shown with the first opening of the app after download. Additionally, during the first use of the app users are asked to set the time for the first type of push notifications (on a pre-defined time) and the duration between reaching a specific location and being asked to get active/start a fitness routine (i.e. 30 minutes after arriving at home) for the location-based notifications. This is to help the user to not only adapt to the notifications but also understand the reasoning behind each type of notification. We



(a) (b)

Figure 25: Screenshots of new features of the *5 mins* app. (a) Welcome page; A new inspirational quote is shown daily. (b) Achievements tab. When the progress bar for a badge is completed, it will be moved to the achieved section and its appearance will modify accordingly;

hypothesize that this might result in an improvement of engagement and likeability of the app since users might feel more informed about how it is functioning. This may also lead the user to trust the *5 mins* app more. These questions will be explored in future work.

Chapter 5

Gamification and Multimodal Cueing in Physical Therapy

A version of this chapter was submitted to the 2021 International Conference on Information and Communication Technologies for Ageing Well and e-Health.

> Haghbin N., Kersten-Oertel, M. Gamification and Multimodal Cueing in Physical Therapy and Rehabilitation, *submitted to the International Conference on Information and Communication Technologies for Ageing Well and e-Health (ICT4AWE 2021).*

5.1 Introduction

In guided fitness and physiotherapy, concise instructions and feedback are needed so that patients can both safely and effectively execute specific exercises. Cueing from a professional is one of the known methods of guidance in physical therapy which can help a patient to perform activities more effectively. More specifically cueing has been defined as using stimuli (either temporal or spatial) to help in the start or continuation of a movement [40] or simply as giving information as to what a particular exercise should look like or how it should be carried out [66]. As described in Chapter 3, there are different types of cues including visual (e.g. arrows or lines on the floor showing which way to walk), auditory (e.g. spoken instructions), or somatosensory (e.g. vibrations on a wearable).

In this chapter, we describe an experiment that was conducted for investigating what type of real-time cueing (i.e. visual or auditory) can improve gamified physiotherapy exercises. Physiotherapy can be a painful and tiring process involving a series of exercises that patients must repeat over a long period. Unfortunately, patients often get bored after a short period of time and lose motivation making physiotherapy less effective. Furthermore, patients doing exercises at home may not have access to the cueing and feedback they would typically have when working in a clinic with a professional.

One solution that has been widely used in recent years to encourage patients to do their exercises at home is the use of video games and mixed reality (e.g. augmented or virtual reality). Using the gamification paradigm in physiotherapy can make the process more entertaining, engaging and can help to keep patients motivated. Video games can also be an ideal medium to incorporate physiotherapy exercises with different cueing modalities. Although studies have shown the efficacy of physiotherapy can be improved by the addition of cueing techniques [40], the use of an inappropriate modality or excessive information, which may be the case when using multiple modalities, may lead to excessive cognitive workload. While multimodal cueing can keep patients informed, engaged, and even entertained, excessive information can be distracting, and confusing [67]. Thus a balance needs to be found to determine which cues or which combination of cues can provide motivation and help a patient to effectively perform their exercises.

To study the impact of both gamification and cueing for use in physiotherapy, we developed *Neblina Wrist Physio*, an iOS mobile application consisting of two well-known games (*Breakout* and *Flappy Bird*). *Neblina Wrist Physio* works with Motsai's Neblina™ sensor [1] to help users do simple wrist workouts (see Figure 26).

5.1.1 Neblina Motion Sensor

The Neblina™ core module is a low-power self-contained Attitude and Heading Reference System (AHRS), Inertial Measurement Unit (IMU), and Vertical Reference Unit (VRU) module with wireless connectivity developed by Motsai. It uses a Bluetooth connection to connect to smartphones, tablets and other devices. It also has extremely efficient power management and low-energy operation making it ideal for

[1] https://motsai.com/solutions/neblina/

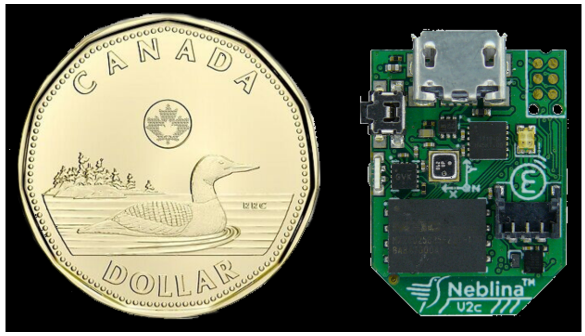


Figure 26: The Neblina™ motion sensor compared to a Canadian one-dollar coin size-wise.

exploring motion in wearable technology devices [68].

For our research, we used the AHRS functionality of Neblina™. An AHRS system consists of sensors on three axes that provide attitude information for aircraft, including roll, pitch, and yaw (Figure 27). The yaw axis has its origin at the center of gravity and is directed towards the bottom of the aircraft. The pitch axis has its origin at the center of gravity and is directed to the right, parallel to a line drawn from wingtip to wingtip. The roll axis has its origin at the center of gravity and is directed forward.

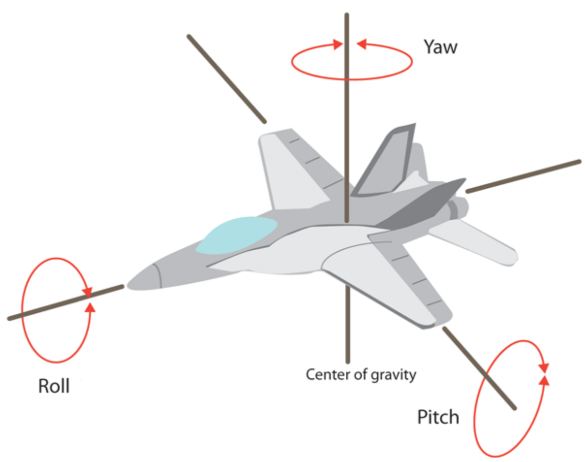
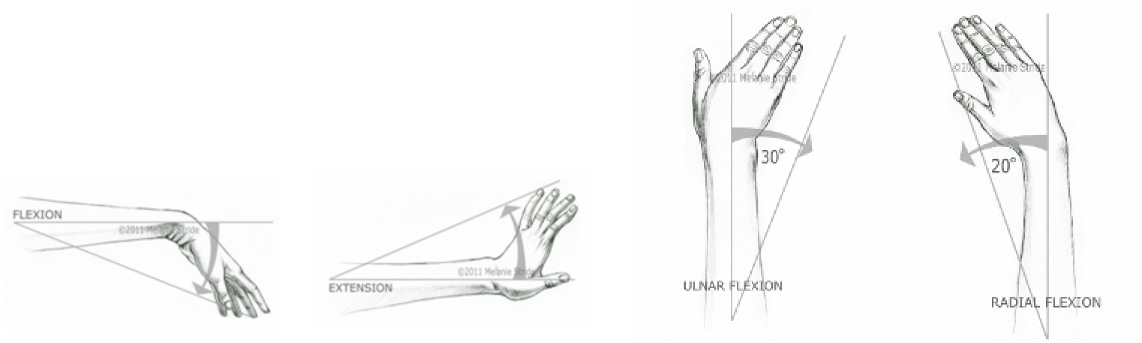


Figure 27: Roll, pitch and yaw in an aircraft. Figure from [69] with minor modifications.

5.2 Wrist Physiotherapy Exercises

Wrist injuries or wrist pains are very common in people who do sports or people who do repetitive wrist motions (e.g. typing on a keyboard or working on an assembly line). In addition, wrist pain might be a result of sudden impacts or certain diseases such as rheumatoid arthritis, which mostly affects the elderly. Physical therapy is known as one of the common treatments for wrist disorders. Moreover, performing simple stretching and strengthening exercises regularly or as warm-ups before doing sports can help to prevent wrist injuries [70].

Two of the most common sets of wrist physiotherapy exercises are extension and flexion of the wrist and ulnar and radial deviations. Extension is defined as raising the back of the hand and flexion describes the bending of the hand down so that the palm faces in toward the arm (Figure 28a). Ulnar deviation is the movement of bending the wrist towards the little finger's side. Radial deviation is the movement of bending the wrist towards the thumb's side (Figure 28b). Normal values for wrist range of motions are 71 degrees of extension, 73 degrees of flexion, 33 degrees of ulnar deviation, and 19 degrees of radial deviation [71].



(a) (b)

Figure 28: (a) Extension and Flexion. (b) Ulnar and Radial deviation. Figures from [72];

5.3 User Study

To study the impact of gamification and cueing modality preferences and on physiotherapy exercise, we developed a wrist therapy game with different cueing modalities: visual, auditory and visual and auditory cues combined. The study involved participants playing two video games on an iPad while having the Neblina$^{\text{TM}}$ sensor placed on top of their hand as can be seen in Figure 29.

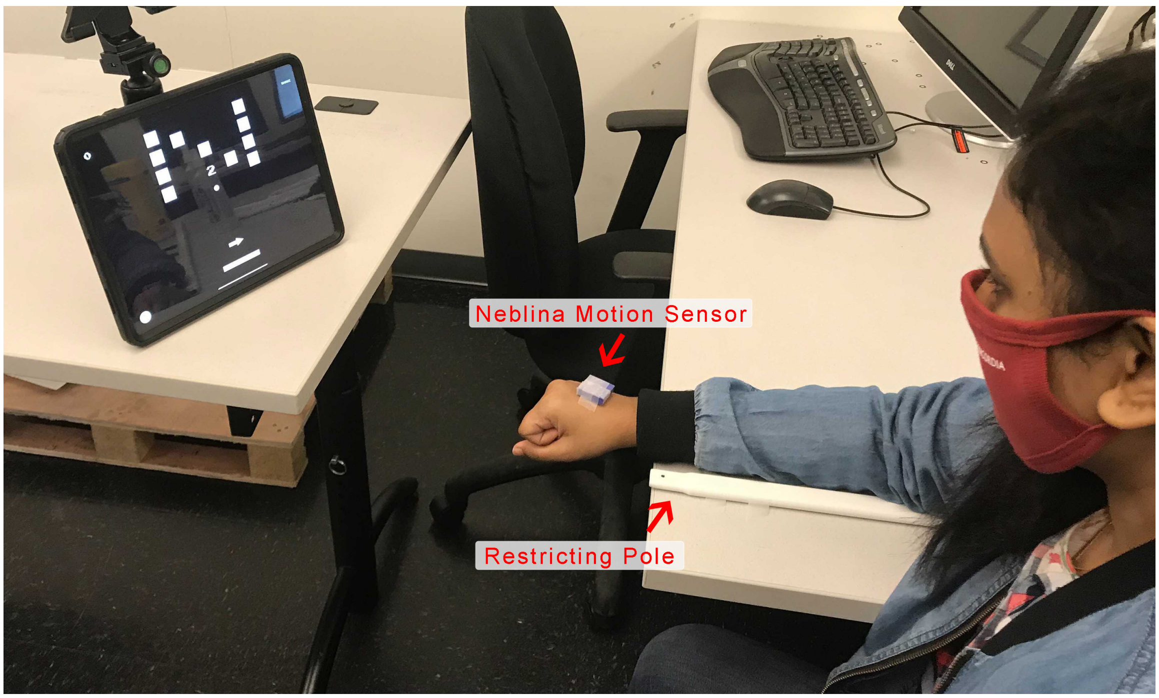


Figure 29: Setup of the user experiment.

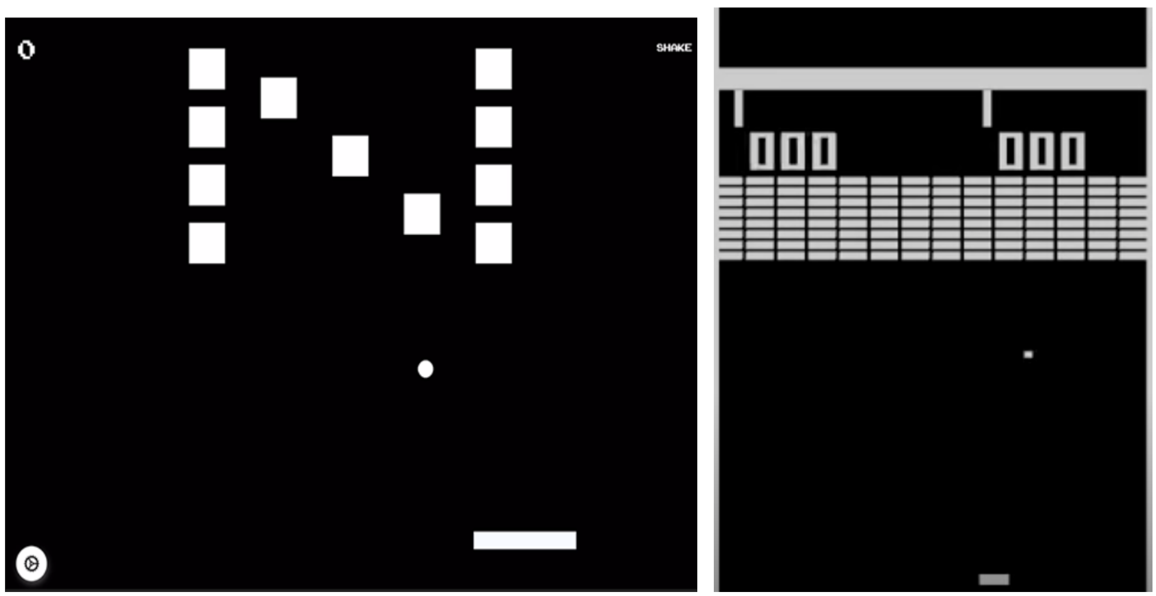
Specifically, we had the following research questions: *Which cueing modalities (no cueing, audio, visual, or a combination of audio and visual) are best to improve physiotherapy exercise quality in a gamified environment?* and *Do users have fun and become engaged in physiotherapy exercises when they are gamified?*

5.3.1 *Neblina Wrist Physio* App

To answer our research questions, we developed an iOS application consisting of two video games that are used for basic wrist physiotherapy: *Breakout* and *Flappy Bird* [73, 74, 75].

Breakout Game

Breakout is based on the popular arcade game with the same name (Figure 30). In this game, the user controls a paddle at the bottom of the screen to keep a ball from falling while popping blocks at the top of the screen using the same ball. In our version of the game, the paddle is controlled by Neblina™ sensor which is placed on top of the user's hand. Thus, the user has to do ulnar and radial deviations in order to play the game.



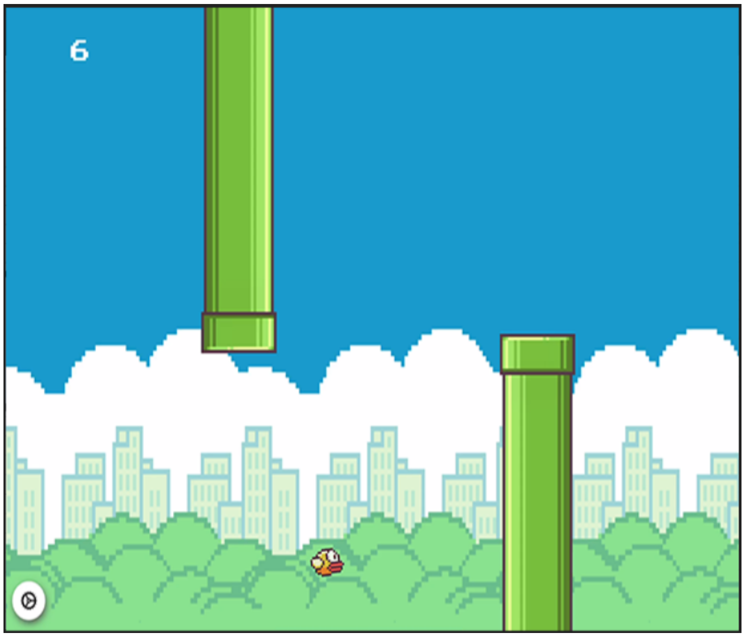
(a) (b)

Figure 30: Screenshots of the *Breakout* game. (a) The *Breakout* game in *Neblina Wrist Physio* app. (b) The original *Breakout* game. Figure from [76];

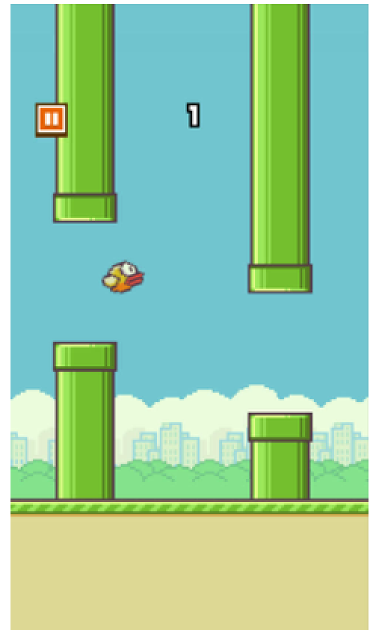
In the *Breakout* game the visual cue was given by arrows that pointed to the left or right indicating where the paddle needed to be moved to hit the ball. For auditory cueing, a voice saying "Move left" or "Move right" speaks while the ball moves downward indicating where the paddle needs to be moved. We also studied the combination of both cues.

Flappy Bird

Flappy Bird is a game, where traditionally, the user controls the bird by tapping on the screen and avoiding pipes appearing in the way (Figure 31). In our version of



(a)



(b)

Figure 31: Screenshots of the *Flappy Bird* game. (a) The *Flappy Bird* game in *Neblina Wrist Physio* app. (b) The original *Flappy Bird* game. Figure from [77];

the game, the bird is controlled by extension and flexion of the user's wrist. In this game, extension of the wrist makes the bird fly higher and flexion of the wrist makes the bird fly lower (Figure 28a). For this game, visual cueing was given using arrows pointing up or down while the bird is approaching a pipe and audio cueing was done by having a voice say "Move up" or "Move down" while the bird is approaching a pipe. The combination of cues was also studied.

5.3.2 Experimental Design

The setup for the user experiment required the user to place their right arm comfortably on a desk. A preliminary study showed that participants playing Breakout would tend to move their whole arm rather than just the wrist, therefore, two horizontal poles were taped to the desk to limit the movement of the user's arm. To perform the exercises correctly, the user's arm should stay still on a flat surface, thus the participants were instructed to leave their arm flat on the table and only use their wrist to move within the games. The participant's wrist was not placed on the desk so that it could move freely without any restrictions (Figure 29). In addition, for both games, the user can perform the exercises while making a fist or having their hand flat.

In both games, the Neblina^{TM} sensor was placed on top of the user's hand and the speed of the game and sensitivity of the sensor was calibrated for each participant. After participants filled out the pretest questionnaire, and prior to playing the game, users were first instructed on how to do the exercises and then asked to do each exercise without the system for 30 seconds. Each participant played each game for 2 minutes under four conditions: (1) no cue, (2) visual cue, (3) auditory cue and (4) visual and auditory cue combined. Thus each participant played 8 minutes of each game. The ordering of which game was played first, *Breakout* or *Flappy Bird* was alternated. Participants were able to rest before each round of the game and were told they should stop at any time if they experienced any discomfort.

Pre-test Questionnaire

Prior to playing the game, participants signed a consent form and filled out a pre-test questionnaire containing questions about participants' experience with wearable sensors, video games, and guided exercising. Example questions from the questionnaire include:

- *Have you done guided exercises or rehabilitation before?*
- *How often do you play video games?*
- *Do you have any experience working with wearable devices containing motion sensors (e.g. HMD, Smartwatch, Smart clothing etc.)?*
- *Do you have any experience doing "gamified" fitness activities (e.g. Wii Sports, Kinect Sport Games, Zombie Run, Ingress, etc.)?*

The full questionnaire was created using Google Forms and can be accessed at https://forms.gle/uGLAxVFxrkkkY8gX7.

Post-test Questionnaire

After finishing the experiment, participants were asked to fill out a post-test questionnaire. In the post-study questionnaire we targeted participants' preference and feeling regarding cueing modalities for each game, and their perception of wearable sensors and the use of games for physiotherapy. In addition, they were asked about any further suggestions for improving the application. The post-test questionnaire can be accessed at:https://forms.gle/J5xYSUZXeL5yZVyUA

5.4 Results: User Study

For the study, 10 healthy participants (4 females and 6 males, age 24 to 44) were recruited[2]. None of them had any major hearing, vision or wrist problems.

5.4.1 Pre-test Questionnaire

According to the pre-test questionnaire, half (50%) of the participants love new technologies and try using them and 20% of them like new technologies but are not eager to use them. The rest of the participants might like or dislike them depending on the context (see Figure 33a). Regarding experience with guided exercises or physiotherapy of any kind, 70% of the participants did not have any experience. Twenty percent of the participants had experience with conventional guidance methods, for example with paper instructions (e.g. sheet with physiotherapy exercises), a professional demonstrating exercises (e.g. in an aerobics class), and video instructions (e.g. a yoga Youtube video). Lastly, another twenty percent had experience using guidance with movement trackers or sensors. None of our participants had experience in doing guided exercises with augmented or virtual reality (see Figure 32).

The pre-test questionnaire also showed that the general perception of gamified fitness activities was positive. From the 30% of participants who had experience with them, 66.6% believed that they cannot be effective in improving general health but they are motivating. All of the participants believed that they are fun, engaging and interesting. Participants generally disagreed that games are frustrating, stressful or discouraging. On the contrary, subjects who had experience with team gamified fitness activities (20%) believed that doing fitness activities with a team in a gamified way can improve fitness and general health.

[2]Due to the COVID-19 pandemic and partial lock-down in Montreal at the time, we could only run subjects from within our bubble, thus limiting the study size and our ability to recruit subjects currently doing arm/wrist physiotherapy exercises.

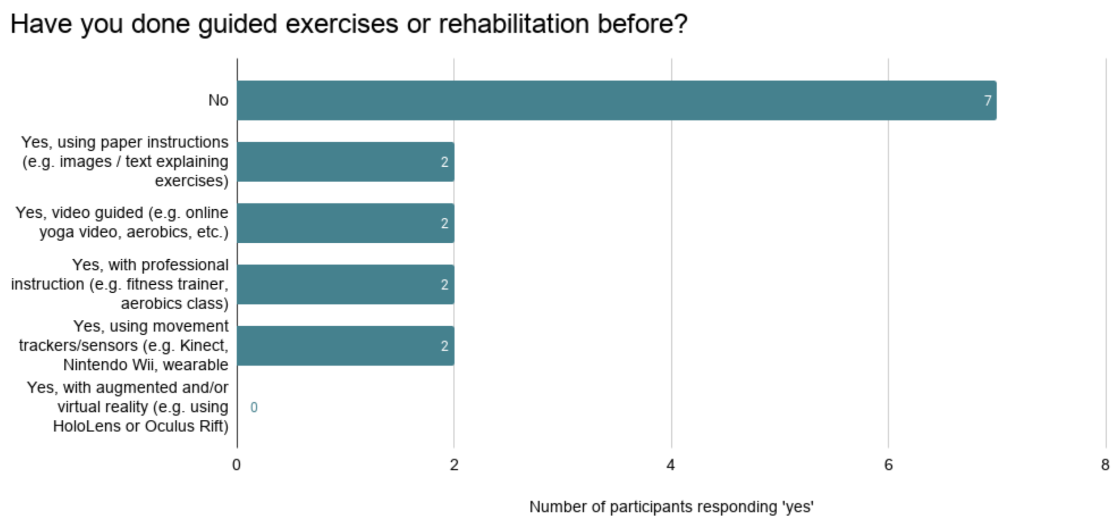


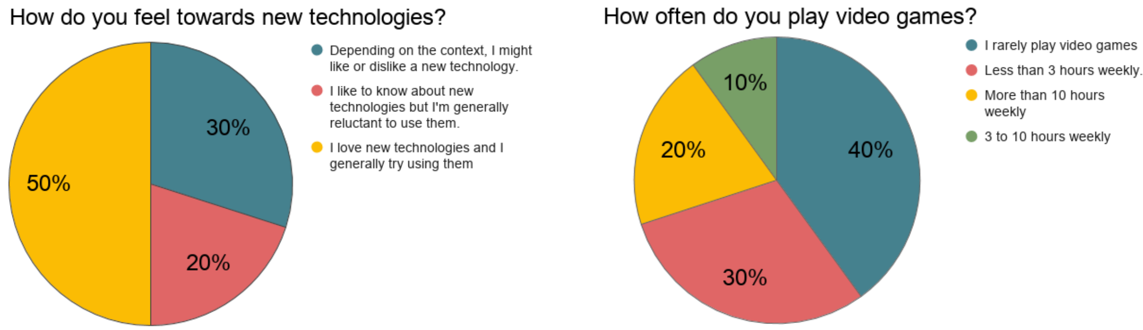
Figure 32: Users' prior experience with guided exercises or rehabilitation.

Regarding the use of video games, almost half of the participants (40%) rarely played video games. Twenty percent of them played video games more than 10 hours weekly and 30% of the participants played video games less than 3 hours weekly. 10% of the participants played 3 to 10 hours weekly (see Figure 33b). The majority of the participants (80%) used mobile devices for playing games. Almost half, 40% use a Desktop and laptop to play and 10% of the participants use a video game console. With respect to the participants' general feeling during game playing, 70% of them felt entertained, 40% of them felt excited and another 40% felt relaxed. These differences of feelings could be due to differences in the type of gameplay (e.g. Tetris/Sudoku type games versus first-person shooter games).

In terms of wearables, we found that 70% of our participants have previously used a wearable device containing motion sensors (e.g. HMD, smartwatch, smart clothing) and 80% of them had experience with motion-sensing devices (e.g. Kinect and Wii).

5.4.2 Wearable Sensor

The post-test questionnaire queried users perception of the Neblina™ sensor. Participants were asked to rate the precision on a scale of 1 to 5, five being very precise. We found that 90% of the participants rated the precision of the sensor to be greater than 3. The majority of participants (70%) believed that the sensor was easy to use



(a) (b)

Figure 33: (a) Users' feeling towards new technologies. (b) The amount of time users spend playing video games.

and all of them felt comfortable using the sensor.

5.4.3 Perception of Gamified Physiotherapy

Generally, the participants favoured the idea of using a game for doing physiotherapy exercises. They all felt motivated and 90% of them felt that the study was fun to use, engaging, and effective; however, almost half of the participants (40%) felt the overall system was difficult to work with. At the same time, all of the participants responded that they would use this type of system for physiotherapy or rehabilitation.

Regarding subjects' feelings during playing the *Breakout* game, albeit they mostly had positive feelings such as entertained (50%), excited (40%), happy (10%), had fun (10%), and were engaged (10%), 30% of the participants felt stressed and one subject felt bored. This result is more or less the same for the *Flappy Bird* game with one major difference, that nobody felt stressed during this game while 40% of the participants felt relaxed during this game. In addition, fewer participants felt excited and more felt bored. These results could have been expected since during the user study, the *Breakout* game was perceived to be more challenging for the participants in comparison to the *Flappy Bird* game. Comparing to their usual feelings regarding video games, for the *Breakout* game the same participants that felt excited or stressed had answered in the pre-test questionnaire that games typically make them stressed or excited. Thus, these participants had the same perception of the physiotherapy games as for typical games played for leisure. Those participants who play games more often felt less entertained and more bored during the study since the main goal of these games is performing physical therapy exercises rather than entertaining users (Figure 34). Furthermore, based on the post-study questionnaire, less excitement for a game might result in boredom during the game (Figure 34).

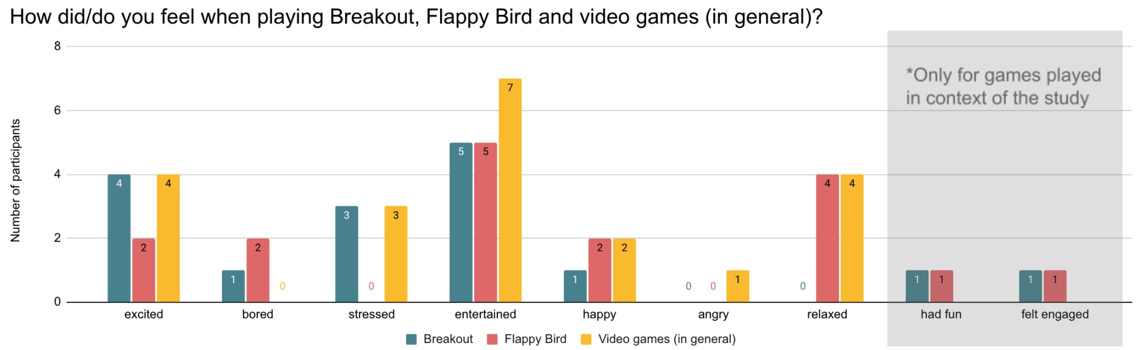


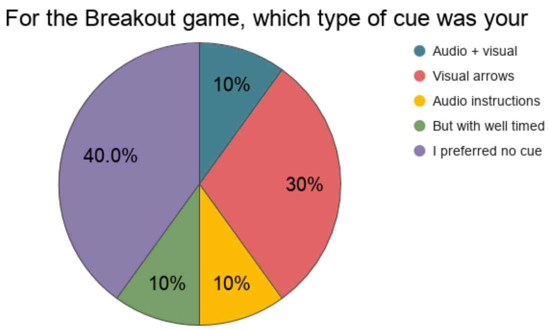
Figure 34: Users' feeling while playing *Neblina Wrist Physio* games.

5.4.4 Exercise Quality

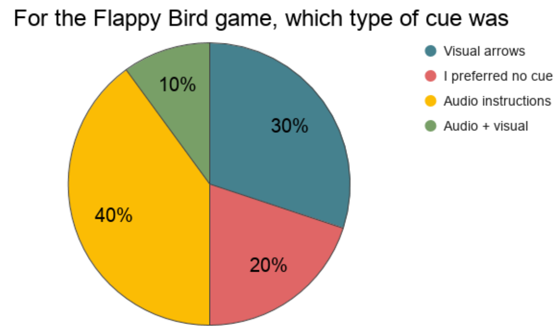
Although we did not directly measure the quality of the wrist exercises we did observe participants. Although during the game, participants were asked try to not move their arm and only use their wrists for the exercises in some cases of the *Breakout* game, they tended to shift their arm or rotate their wrists instead of doing ulnar and radial deviation in order to avoid losing. This might be directly connected to their level of excitement or stress while playing the game. We posit that the more engaged users become the more likely they are to focus on gaining points and doing well in the game than doing the exercise properly.

5.4.5 Cueing

We queried the users on their preference about cueing modality in terms of engagement, helpfulness in performance, and distraction. Overall, the favourite cue for *Flappy Bird* game was the auditory cue (40%), in comparison to no cueing for the *Breakout* game (Figure 35). A T-test showed that there were no significant differences between the two games in terms of users' opinion of cueing modalities (visual ($p=0.4263$), audio ($p=0.3375$), audio + visual ($p=0.4766$)). We summarize the results of the main findings in Figure 36.



(a)



(b)

Figure 35: Users' preference regarding the type of cueing. (a) For the *Breakout* game. One participant preferred the combination of audio and visual, provided that they are timed better. (b) For the *Flappy Bird* game.

Visual Cueing

For the *Breakout* game the majority of participants felt that visual cues were not distracting (70%) or annoying (80%). In addition, half of the participants sensed an improvement in their performance, and 40% of them felt it was helpful. For the *Flappy Bird* game, fewer participants (40%) felt the visual cue had a role in improving their performance but more subjects (50%) sensed it was helpful. Almost all of the participants agreed that the visual cues were not distracting (90%) or annoying (80%) for the *Flappy Bird* game. The major difference regarding visual cues between the games was the level of engagement; 30% of the participants thought that the visual cues had made the *Breakout* game more engaging, whereas this result is 50% for the *Flappy Bird* game. This difference is also likely due to the difference in the difficulty of the games. One participant commented that the *Breakout* game was more difficult so the cues helped, whereas, for the *Flappy Bird*, which is more simple and easy to play, the cue had no impact and therefore was ignored.

Audio Cueing

For both games over a third of the participants (40%) felt that auditory cueing was annoying. This might be as a result of the fact that participants were focused on the visual elements of the games and having audio cues repeating ("up/down" or "left/right") became annoying. At the same time, the cues were deemed helpful and improved users' performances. Thus it seems they did not negatively impact the users' game performance. For both the *Breakout* game and *Flappy Bird* game, half of the participants felt an improvement in their performance comparing to visual cueing rounds. Half of the participants felt audio cueing was helpful for the *Breakout* game and this number increased for the *Flappy Bird* game to 70% which is higher than the visual cueing as well. The majority of the participants agreed that audio cues were not distracting when playing *Flappy Bird* game (80%) or the *Breakout* game (70%). A major difference regarding the level of engagement with audio cues between the games was apparent. In terms of engagement, 40% of the participants felt that audio cues had made the *Breakout* game more engaging and 70% felt that for the *Flappy Bird* game.

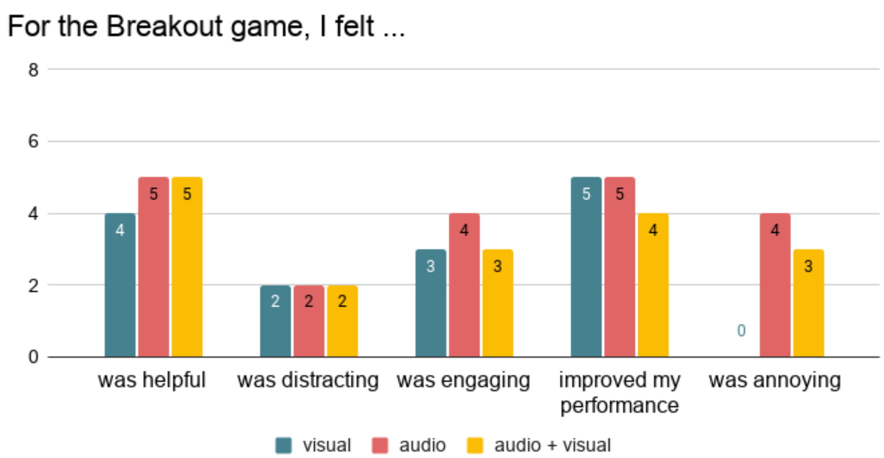
Multimodal Cueing: Visual and Audio

In terms of the users' perception with both of the cue modalities, the *Flappy Bird* game showed more promising results. While the combination of visual and audio cues resulted in the same perception for helpfulness (50%) and distraction (20%) for both of the games, the *Flappy Bird* game with two modalities was considered more engaging (50%) and more effective regarding performance improvement (50%) compared to the *Breakout* game with both of the modalities. In addition, the *Flappy Bird* game was found to be less annoying (20%) than the *Breakout* game (30%).

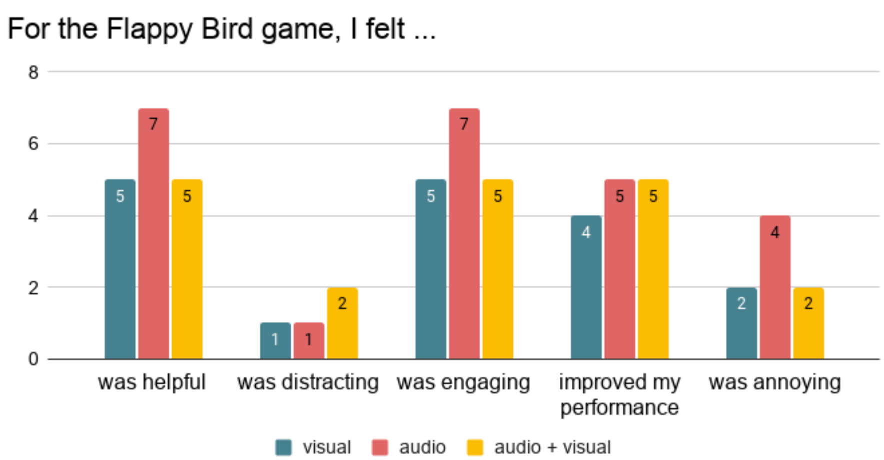
5.5 Discussion and Conclusions

The results of our work suggest that people believe gamified physiotherapy is engaging and can improve exercises. However, the design of these types of games requires its own set of considerations and its level of difficulty needs to be customized based on each individual's capabilities. Furthermore, consideration into using cueing for better timing and smoothness of the exercise should be considered in future work [78]. In addition, the impact of cueing on cognitive load needs to be customized as well. As one of the participants mentioned "... I ignore them [visual cues for the Breakout game] because it takes longer for me to process visual cues than play based on my assumptions...".

Although our population believed that more challenging games might be more



(a)



(b)

Figure 36: Users' opinion of types of cueing. (a) For the *Breakout* game. (b) For the *Flappy Bird* game.

exciting and engaging, this may not be the case with an elderly population. With more engaging games people might pay more attention to scoring rather than correctly performing the physiotherapy exercises. Thus, for more engaging games a possibility for future work would be to include pose estimation and use feedback to show a user when an exercise is not being performed correctly [79, 80, 81].

In terms of limitations, the user study was conducted in COVID-19 conditions. Since this study required participants to place a wearable sensor on their hands, it was limited us in terms of finding more participants from diverse backgrounds. Lastly, our study only included two cueing modalities (i.e. visual cueing and auditory cueing). The next step of this work will be to not only explore the effect of haptic cueing and combination of haptic with auditory and visual cueing, but also the effect of feedback modalities on basic and more challenging physical therapy exercises. Moreover, we will use in-game scores as a quantitative measure for assessing users' performance.

Chapter 6

Conclusion

In this dissertation, we investigated gamification, notifications and cueing in the context of mhealth and physiotherapy applications. Specifically, we first looked at if context-aware push notifications can affect users' level of motivation to exercise and encourage them to be more physically active. To answer this research question, we developed an iOS mobile fitness application with the ability to send context-aware push notifications. Our results showed that push notifications in any context require consideration of that context's special set of characteristics in order to neither impact a user negatively nor be ignored. Regarding the specific context of health and fitness, people tend to favour being reminded to be more active; however, these reminders need to have dynamic content and be received at times that the user has not been active enough.

We also explored if cueing can affect the quality of and engagement in physiotherapy exercises in a gamified environment. For this second research question, we developed an iOS application consisting of two video games aimed at basic wrist physiotherapy exercises. The application works with Motsai's Neblina™ wearable sensor. The results of our study showed that gamified physiotherapy can be used to help users perform their exercises provided that a games' level of difficulty and cueing timings are customized based on each individual's physical and cognitive capabilities. Furthermore, our findings show that gamification can make the physiotherapy process more engaging. Hence, users will be more motivated to adhere to their therapy routines.

Overall, our findings show the importance of fine-tuning both notifications and cueing strategies. Whereas well-timed notifications and multimodal cueing can provide motivation and help encourage an end-user, poor methods may discourage users from being active and performing their exercises correctly.

6.1 Future Work

The next step to determine the impact of context-aware push notifications on individuals' level of motivation for doing fitness workouts would be to run a long-term study with the improvements made to *5 mins* (described in Section 4.7 of Chapter 2). During a long-term study, users would have the time to form a habit of doing exercises if they are motivated enough. In addition, this study would include a larger, more diverse number of participants.

In terms of privacy, in our participant population, which had a majority of technologically savvy participants, the respondents were concerned with their privacy and were not willing to give apps full authorization to collect their data in the background. It will be interesting to see in future work if similar trends exist in a more diverse population. A potential solution for privacy concerns is to have a better explanation of why different sensors (i.e. GPS) are used and how they can improve the timing and content of push notifications. More details about why, when and how data is collected can be given in *5 mins* during on-boarding or the pre-test interviews.

There is considerable research potential regarding providing guidance in a virtual environment for physiotherapy exercises. In addition, the emergence of computer vision methods and wearable motion tracking devices has provided various ways of collecting users' movement data. Still, several concerns remain that need to be addressed regarding the clinical effects of cueing and other forms of guidance on gamified physiotherapy movements. Most prominently, we currently lack understanding of the connection between in-game performance and cueing and whether this in turn impacts enjoyment and ultimately adherence to physiotherapy routines. Although our study shows promising results regarding the use of cueing with basic gamified physiotherapy exercises and a healthy population, it is currently unclear whether our method will hold true for a more complex physiotherapy routine and for participants who present with motor deficits and are going through an actual physiotherapy process. In addition, since a number of physical therapy exercises need the patient to be more active and move more often during an exercise, the use of other cueing modalities such as haptics might be more beneficial than visual cues. Moreover, providing feedback to show if the user is performing exercises correctly can continuously improves the users' performance as was demonstrated in previous studies [82, 79]. Future investigations should examine whether having feedback along with cueing can have the same or even a stronger effect on users' adherence to routines and quality of movements and exercises.

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