Incremental Design of Therapeutic Music Games: Theory and Application to the Treatment of Behavioral Disorders and Alzheimer's Disease

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Contents

Introduction

It is standard practice to introduce works dealing with music by stating that it may very well be the oldest form of art known to man, that there is no known culture that does not have some form of musical expression or that musical sensitivity seems to be so profoundly hard-wired into almost all human beings that even babies in the womb have been shown to respond to musical stimulation. However, to the best of our knowledge, no one has yet started a book with this very simple remark: as of September 2010, a Google search for the term "music" returns about 2 640 000 000 results, which is more than twice as much as "art" (1 020 000 000), about 3 times as much as "movies" (801 000 000) and nearly 30 times as much as "painting" (93 600 000). Oddly enough, "music" even beats "food OR sex" (2 560 000 000) by a comfortable hundred billion.

Besides being somewhat counter-intuitive for anyone slightly familiar with human nature, these figures highlight the prominent place that music holds in our society. The latest technological developments have in fact made it so pervasive in our everyday lives that it is no longer impolite for teenagers to have music playing in their headphones at all times, even during a heated debate about the best way to get back at their teachers for forcing them to learn something as useless as mathematics. However, in spite of the countless hours that many of the most brilliant minds ever to walk the Earth have spent dissecting what is arguably the single most popular of all the art forms that humanity has ever created, we are still far from being able to answer questions as basic as "What makes music pleasurable?" or "What makes a musical piece beautiful?" or even "What is music, exactly?".

Although the quest for a definite answer to any of these questions is obviously hopeless, since even the most serious studies yield results that are fuzzy at best, we already do know a great deal about matters as diverse as music's unspoken rules that derive from mathematics [1], how it affects our brains and our cognition [2] or what evolutionary advantages our musical sensitivity might have given us [3]. These topics are investigated and debated every day by thousands of musicologists, neuroscientists, artists, philosophers, businessmen, sociologists and so on, whose results invariably surprise us and tend to raise far more new issues than they solve, making the study of music one of the most open and vibrant research fields today.

Music Therapy

Among the many people whose life revolves around music, music therapists have a special place: they are probably those with the biggest faith in its extraordinary powers. They try to use it to help patients suffering from virtually any illness, many of which remain incurable, and routinely obtain outstanding results that seem to defy our understanding of the workings of our bodies and brains [4].

The techniques they use are in constant evolution but the approach itself is nothing new, as the therapeutic power of music was already recognized in ancient times: the bible mentions David playing the harp to heal King Saul's depression and explicit endorsements of music therapy can be found in the writings of Plato, Aristotle, Confucius and many others among the greatest thinkers of all time. However, in the modern healthcare community, this treatment method has often been met with very strong skepticism, as physicians focused on drug-based therapies and more or less completely disregarded everything else. Only today is music therapy finally gaining widespread acceptance, thanks to its now increasingly acknowledged positive results with conditions such as Autism and Alzheimer's disease, for which very few alternative treatments exist.

A likely cause of music therapists' constant struggle for recognition is the extremely variable impact of their technique on patients, whose responses to the treatment often depend much more on their personal history and tastes than on the nature of their conditions. Such a high variability makes it extremely difficult to conduct quality quantitative assessments of music therapy. Moreover, there are countless sensible ways to use music therapeutically and, because of this lack of quantitative studies, it is more or less impossible to make serious comparisons between the different approaches that therapists use. Thus, a myriad of music therapy flavors and techniques exist, something which may be quite confusing even for healthcare practitioners who most of the time get very little information about art therapy in general during their studies.

There are two basic categories of music therapy techniques: receptive (RMT) and active (AMT). Receptive approaches have patients listen to carefully chosen music, most of the time in an environment prepared by the music therapist as part of the intervention. For example, in S. Guétin's U-Cycle receptive music therapy [5], patients listen to music lying down on their bed, with headphones on their ears and their eyes closed. The therapist stands next to them and plays music chosen to fit their tastes and at the same time take them through the U cycle: first very energetic and powerful music, then progressively more relaxed pieces until they reach an almost meditative state and finally livelier but still soothing music that wakes them back up into a state of awareness and relief. This technique has been shown to reduce suffering in patients with chronic pain as well as anxiety in patients suffering from brain injury and Alzheimer's disease [6], [7], [8].

Guétin's work alone demonstrates the versatility of music therapy. However he is far from being the only one to use receptive music therapy, which has also been shown to reduce anxiety and improve mood in hospitalized patients [9] and even to significantly reduce self-reported pain in various clinical contexts [10]. Overall, receptive techniques have a moderate but significant impact on patients' well-being. Given its extremely easy implementation, which often requires nothing more than handing a music player and a pair of headphones to patients, RMT is an almost automatic recommendation as a complementary treatment for virtually any condition.

One must nevertheless note that having a well-trained music therapist choosing the music achieves significantly better results. It makes it possible to organize sessions more precisely, as in U-cycle therapy, but also to use more advanced techniques such as Guided Musical Imagery [11] or other analytical techniques, where music becomes a medium that supports interaction between client and therapist. Then, it is no longer the act of listening to music itself but the discussion that follows that is therapeutic, as it addresses concerns that have been uncovered through music.

The second type of approach, active music therapy, has patients actively participate in the music creation process. Most often, therapists have them sing and clap, but many techniques also include playing basic instruments or body percussions, composing melodies, writing lyrics or even arranging for the group. Again, there are countless AMT techniques from which therapists pick the most suitable for their patients according to their tastes and general information about their pathology. However, it is important to remember that the nature of the music that will be played is largely independent from the technique chosen, since music therapists always strive to free themselves and their patients from any cultural bias and use whatever kind of music works.

It would be far too long to exhaustively cover even just the most prominent AMT techniques that exist, especially since many are quite poorly documented. One thing that we can do however, to give readers a good feel of what AMT encompasses, is to take a closer look at three important dichotomies that we see among music therapy techniques and examine their medical impact.

First, AMT can be either improvisational or compositional. In improvisational music therapy [12], patients create music on the spot, using their voice, instruments, body percussions or even every day objects that the therapist makes available, depending on their preferences. This kind of intervention is useful for patients who need to practice real-time skills such as attention, sensori-motor coordination, decision making and so on [13]. Renaud Michel's protocol, described at length in Part II, is a very good example of an improvisational technique. On the other hand, compositional music therapy puts emphasis on "offline" music creation: patients compose melodies and even entire songs, usually using computer music software under close supervision of their therapist, or write lyrics that typically talk about their personal issues. Such compositional techniques have been used to reduce depression in prisoners through the assisted composition and recording of rap songs [14] or even with patients suffering from Alzheimer's disease, who in spite of their memory deficits proved capable of composing and remembering a song featuring their name and various facts about themselves [15].

Second, AMT is either performed in duo sessions, with just one client and the therapist, or in groups that can involve 10 patients or more, although beyond that limit things tend to become unmanageable for a single therapist. Maybe surprisingly, since music making is an inherently social process, duo sessions are the most common. They allow therapists to start a musical conversation with their patient, most frequently by playing or singing motifs that either invite completion from the client or respond to his or her performance to encourage further playing. Solo sessions are most of the time used with the most severe patients, who require a lot of attention and need specific care or simply could not possibly be expected to interact positively with other players in group therapy. Nordoff's approach [16], which uses musical education as a therapeutic means, is a very good example of such a technique. On the contrary, group sessions emphasize interaction between patients, while therapists are mostly confined to an organizational role, acting as facilitators when the group seems unable to go on by itself. This approach is recommended for patients with poor social skills or simply as a way to cut costs by treating several patients at a time. Additionally, it can be used with preexisting groups such as colleagues from the same company, sports teams or families to reveal and solve unspoken conflicts or simply foster a collaborative dynamic [17].

Third and last, music therapists may adopt a preferentially behavioral or psycho-dynamical stance depending on their goals. Contrarily to the two other dichotomies we mentioned, there is a continuum here: virtually all AMT techniques have both behavioral and psycho-dynamical components. For example, since their impulsiveness greatly hinders their ability to function socially, Michel's group therapy for children with behavioral disorders can be considered as a form of exposure therapy, even though the approach as a whole is grounded on analytical principles, since it derives from Lecourt's Sonorous Communication [17]. Similarly, any behaviorally-oriented approach, even if it strongly focuses on reinforcement training and similar techniques based on strictly quantitative evaluation, is bound to elicit emotional responses from clients in relation with their musical preferences and sonorous history. As long as achieving peaceful communication is one of the objectives of the treatment, which is almost invariably the case with agitated children for example, behavioral therapists will encourage clients to talk about their musical feelings, effectively triggering and leveraging psycho-dynamical processes even though this is not their primary intent.

This quick summary of the music therapy landscape shows how versatile it can be and illustrates the staggering diversity of techniques in which music can be put to use. However, in spite of this apparent heterogeneousness, we see one specific characteristic of music that every single technique mentioned above builds upon: its ability to increase motivation and concentration through pleasure and fun. Since that is also one of the most prominent assets of video games, it seems natural to try to build upon this synergy to create "serious" music therapy games.

Serious Games

Serious gaming is a much newer field than music therapy. The term itself seems to have been coined by C. Abt in his book *Serious Games* [18] which was first published in 1970. The members of the serious gaming community however see 2002 as the pivotal year that started the entire movement with the game *America's Army* [19], which was the first to be explicitly "serious" in its goals: the U.S. Army created it with for sole purpose of enhancing its image and recruiting better, more informed people. That does not mean that other games with agendas other than play itself were not released before, such as *Pepsi Invaders* (1983), which was part of an advertising campaign, or educational games such as *The Oregon Trail* (1973) or *Carmen Sandiego* (1985). In fact, the oldest serious game seems to be *OXO*, a tic-tac-toe game that served as an interactive example for a Ph.D. research in 1952 [20].

The expression "serious game" is considered rather unsatisfying by most of the actors of the community, notably because it is too general and is thus very hard to define without unduly including or excluding certain works. However, since a working definition is usually useful if not necessary, even if it is not very compelling, we will use Zyda's [21]:

A computer serious game is a mental contest, played with a computer in accordance with specific rules, that uses entertainment to further government or corporate training, education, health, public policy, and strategic communication objectives.

This should not be taken too literally, as many alternative definitions have been and continue to be proposed, which seems quite natural when one considers the fact that the scientific community does not even agree on what a game actually is. Moreover, as we explain further in this thesis, neither of our projects truly fit with this statement, but we reckon they are close enough to qualify as actual serious games, only with a little twist that is a consequence of their very specific purpose.

Like we did with music therapy, we intend to give a rough overview of the field, so that readers can understand how our work relates to other serious gaming initiatives. More specifically, we want to explain how healthcare games work somewhat oddly compared to other genres of serious games because of their very peculiar target audience. However since we judge the broad classifications that have been attempted informative yet too unsatisfying (see [22], [23]), we simply give a non-exhaustive list of the most important kinds of serious games that we have encountered:

- **Advergames**: games that are conceived and released as an advertising platform. Countless brands have used them recently, but *America's Army* is still the quintessential example.

- **Art Games**: art projects that take the form of a game or rely on game-like mechanics.

- **Edutainment Games**: games that incorporate educational purposes in their objectives. They can be used to teach children or educate the public at large on specific matters. *Food Force* [24] is one of the most popular of these.

- **Exergames**: games that aim at making exercising more fun and enticing, bordering on healthcare gaming. *WiiFit* [25] is by far the most well known.

- **Healthcare Games**: all games that are used for healthcare purposes. This includes rehabilitation games, cognitive training games or even applications like *Pulse!!* [26], which is geared towards physicians, not patients. The community is organized around the Games for Health association [27], a domain-specific emanation of the broader Serious Game Initiative [28].

- **Learning Games**: games that target the acquisition of specific knowledge and aim to maximize its transferability to the real world. They are mostly used for professional formation purposes.

- **Newsgames**: games that illustrate recent events and, optionally, offer an editorial comment.

- **Persuasive Games**: games conceived to change players' attitudes and behaviors through persuasion and social influence. They are mostly used to further public policy agendas. The Games for Change non-profit [29] serves as a coordination platform for many of these efforts.

- **Simulation Games**: games that put players in a virtual yet realistic environment, where they are supposed to accomplish tasks and gain skills or train behaviors that would be too dangerous or too complicated to acquire in a real setting. America's Army and Pulse! belong to this category.

Obviously, these genre definitions are grossly unadapted, at least in the sense that they pertain to very different characteristics of the games, such as purpose for healthcare games and advergames, or gameplay for simulation games, which is why *America's Army* and *Pulse!!* both fit into at least two categories. Nevertheless, this list properly illustrates the sheer variety of applications of serious gaming, which lets us say, along with numerous researchers, futurists and business analysts, that the often foretold complete gamification of life is already well underway.

New Gaming Interfaces for Music Therapy

So how do we gamify healthcare? And more specifically, how do we gamify music therapy? We think the answer lies in the new interfaces that have now become the norm for home entertainment systems. During the short history of video games, there have been many attempts to replace old Atari-style controllers with more enticing and innovative devices, some of which became quite popular like Nintendo's NES Zapper [30]. However the tipping point undoubtedly was the introduction of Nintendo's Wiimote [31], which took over the gaming world in record time. This was a paradigm-shifting event for game-makers, not only because it changed interaction design in games for ever, but maybe even more importantly because it finally made gaming a family hobby, as even the most reluctant non-gamers hardly could refuse a game of *Wii Sports* [32], since it was so easy to play.

The two other giants of the gaming industry have now joined this market to offer their own innovative take on motion-sensing enabled gaming: Sony, with its *Playstation Move* [33], bets on precision, using stereoscopic imaging to provide full 1:1 high-speed motion sensing; Microsoft eliminates the need for a controller altogether with its Kinect device [34], which simply films the player's body to enable gesture-based controls. Moreover, many game-specific controllers are coming out. *Guitar Hero*'s plastic guitar [35] is the most widespread, but many other devices are becoming very popular, such as the Wii Balance Board [36], *Rock Band*'s drum kit and microphone [35] or Dance Dance Revolution's dancing mats [37]. All these interfaces have much better affordance for the games they come with than regular controllers, even the motion-sensing ones mentioned above, and thus help the democratization of gaming by making new games instantly accessible even to non-gamers.

Contributions

In this thesis, we show that new gaming interfaces, of which the Wiimote is simply an example that will eventually be replaced, make it possible to create population-specific music therapy games that are both enticing and accessible, and thus can be used by healthcare practitioners in a real clinical environment. Our three main contributions are:

- A careful analysis of the needs of healthcare practitioners which enables us to highlight the areas in which a music therapy game can provide significant benefits. This can be used to optimize future design efforts by focusing work on the most therapeutically potent features.

- Two games, MAWii and MINWii, and their associated case studies. They exemplify the various caveats that designers of music therapy games must avoid and provide anecdotal yet compelling evidence of what makes a game efficient for working with children with behavioral disorders (MAWii) or with demented patients (MINWii).

- A set of 32 recommendations deduced from the comparison of the two case studies that outline a viable general methodology for healthcare game design. They also provide specific advice to ease and speed up the development and deployment phases and, above all, to maximize the beneficial impact of a music therapy game by making it adequately simple.

Report Structure

In the first part, we discuss our research objectives, review related work and explain the key design and methodological choices that enabled us to reach our objectives. In the second part, we present MAWii, the application we designed with Renaud Michel for him to use during his Sonorous Communication sessions with children suffering from behavioral disorders. In the third part, we discuss MINWii, the game we designed with Dr. Péquignot for the renarcissization of demented patients through music performance. Finally, in the fourth part, we list the 32 guidelines that we propose, based on the common issues that we encountered during our two studies, with one third pertaining to the transferability of knowledge from other fields, one third dealing with the implementation of an Action Research methodology and the last third aiming at making games simpler to be more effective.

Part I

Computer-Assisted Music Therapy

Musicians' quest for inspiration and musical innovation has routinely led them to be among the first professions to make use of technological breakthroughs, especially in the field of electronics: synthesizers, amplifiers, effect processors, computerized samplers and sequencers, sound spatializers and countless others electronic devices arguably started a new age for music since the end of the 1950's [38]. Since most if not all of them are passionate musicians, one would expect music therapists to also be keen on experimenting with all these new devices. However it does not seem to be the case, as only a handful of the numerous protocols and techniques they use explicitly rely on the tremendous capabilities of the not-so-new advances in computer and gaming technology that are now commonplace in many other areas of healthcare as diverse as functional rehabilitation, nutrition monitoring or diabetes treatment.

Therefore, the goal of this work is to investigate the potential benefits of introducing technology and techniques from the worlds of computer music and, most importantly, computer gaming in music therapy setups. Hopefully, our effort will be instrumental in getting music therapists to finally endorse these new technologies, of which they remain very skeptical for now [39]. To this end, we first examine three important directions in which such an approach could enhance traditional music therapy; these will constitute our research objectives. Then, we analyze various previous initiatives in order to pinpoint the issues which prevented other music therapy systems from gaining widespread acceptance and research how analog problems have been tackled in connected fields such as music games. Finally, we motivate the key design and methodological choices we made to establish a flexible framework to orient and simplify the creation of custom solutions adapted to very different types of patients, institutions and treatments.

Chapter 1

Research Objectives

We have classified the numerous advantages we see to blending music therapy with video game technologies and practices in three main categories: motivation, ease of use and data analysis. In this chapter, we will detail these potential enhancements, thereby creating a list of objectives for the systems we design.

1.1 Motivation for a Fun Treatment

One way to define games is to say that they are activities designed to be entertaining without any final utilitarian goal [40]. This statement obviously clashes with our definition of serious games, but it points at something central: games generate motivation without a purpose. Of course additions such as competition and betting also attract players, but one could argue that they already make the game "serious" by giving the outcome extra social and financial consequences so that, in essence, games can be considered as only played for their own sake. Therefore, a good serious game is simply one that hides a specific purpose in an activity which is fun in and of itself.

1.1.1 Games as Catalysts

Making a game, serious or not, is very often both complicated and costly. Therefore, serious games are only used, at least to our knowledge, when increasing a given population's motivation has substantial benefits. *Learning games* motivate users to delve into otherwise rather arid subjects [41]; *advergames* encourage players to watch and listen to advertising content for much longer than they normally would [19]; *simulation games* confront trainees with situations that would be too complex or too stressful to face in reality without significant and demanding training [26].

Healthcare games are no different: they motivate patients, and often their caregivers, to better commit to their treatment in multiple ways. One could in fact argue that healthcare is the one area where motivation is the most important, since even small deviations from proper procedures can sometimes do permanent damage and threaten patients' lives. For example, failure to comply with a painful and demanding physical rehabilitation schedule often results in poor recovery [42], [43]. Even more crucially, allergic children who lack the proper knowledge may unknowingly absorb substances that could be deadly for them, especially since industrial food, because of recent chemical and genetic explorations as well cost reductions, now often contains very unexpected ingredients.

The two previous examples are very good target situations for a serious gaming solution, and they have indeed been addressed in this way [44], [45]. In both cases, existing, effective but tedious treatments are augmented with a fun element that makes it much easier to either cope with the efforts and pain associated with physical rehabilitation or learn simple but unfriendly knowledge about dangerous foods. This solves the dreaded *last mile problem*[1] by shifting the patient's goals from improving his or her health to simply having fun, making the healing process secondary in terms of motivation.

1.1.2 Motivation in Music Therapy

The case for mixing serious gaming with music therapy is not as clear as it is in the situations exposed earlier. Pleasure is already an important part of most if not all music therapy techniques [16] and it consequently does not seem necessary to augment an activity which is already seen as fun and motivating in itself. However, one could also argue that this common characteristic of emphasizing pleasure and fun actually makes a good case for using music therapy and serious gaming together.

First, music therapists are used to making sure that their clients enjoy their treatment, as it would most likely be rather ineffective otherwise. Of course, the goal is not to maximize pleasure at all costs since, especially in analytical therapy, instant, repetitive fun can make patients lose sight of their treatment (see Section 5.1). But giving fun-oriented tools to therapists who are skilled in leveraging and controlling this kind of drive seems like a logical step for promoting the use of serious games in the healthcare world.

Second, the importance of novelty and discovery must not be overlooked. Video games have been around for a long time and can no longer be considered fashionable, as they have now successfully penetrated every segment of the population, with people over 50 making up for an all-time high 26% of the gamer population [46]. However, their use as a tool for things that go beyond entertainment is rather new and exploratory. We think that our

[1] The term *last mile problem* is used to designate a situation where all the requirements in terms of knowledge, technology and infrastructure necessary for an initiative to succeed are fulfilled but end users still fail to benefit from it because of simple distribution and application issues.

target populations will enjoy taking part in this new endeavor as attraction for novelty is often strong in music therapy patients. Indeed, their interest in trying new approaches is often what draws them in to begin with, as music therapy itself remains a rather unconventional treatment. Specifically, we expect that the fun flavor of video games will convince patients skeptical of music therapy to try it nonetheless, even if it is only for the video game side of it. Hopefully, some of them will then discover the surprisingly powerful positive effects music therapy can have and revise their opinion.

Finally, as the tremendous success of recent musical games has shown, the public at large seems to be more attracted to the cultural aspects of musicianship than to actual music creation. For example, many people are willing to spend a great amount of time training on *Guitar Hero* [35] because this game is designed to make players feel like successful rock stars. Training that much on any real instrument would surely make them skilled enough to have fun and play creatively, but the gap between them and their professional idols would also become all too obvious.

Video games give the player an illusion of mastery or even virtuosity which seems to be an efficient motivator. Therefore, we think that using video games to give amateurs access to musical sounds and patterns they could never play with a real instrument should enhance the treatment, even if it means reducing their creative freedom: therapists would be able to leverage this illusion of mastery to fortify their patients' self-esteem and help them explore new musical territories that would be far too demanding without electronic assistance.

1.2 Ease of Use in Rigid Environments

Clinical environments are very rigid. It is arguably almost impossible to make room for disruptive innovation in this kind of setting as even slight changes in routnie protocols often require great efforts in terms of training and planning to ensure the safety of patients and the effectiveness of interventions. Consequently, any tool geared towards clinical practitioners will have to be closely fitted to their needs and their work environment in order to integrate as smoothly as possible in their daily routine. Otherwise, it will probably never actually be used no matter how efficient it may be.

1.2.1 Lowering the Burden and Cost of a Large Instrumentarium

Several of the many music therapy techniques that exist today are rather easy to set up. Receptive music therapy can be implemented in a clinical setting with just a computer and a pair of headphones, provided that the therapist has enough knowledge of the different styles of music that exist to find tunes that fit both the patient's desires and the needs of the treatment

[5]. Therapists who practice duo active music therapy or group singing and body percussion therapy can usually make do with just a guitar or keyboard, although they often also use other small instruments such as shakers when possible [16].

On the contrary, group music therapy sessions such as those practiced in E. Lecourt's *Sonorous Communication Therapy* usually require the therapist to bring quite a large collection of musical instruments [17]. Indeed, it seems obvious that increasing the size of the instrumentarium is usually beneficial in terms of motivation, since it makes it more likely that all of the participants are able to find something they want to play. Moreover, the instruments must represent a large spectrum of ranges and timbres so that the players can easily find their own sound and place in the improvisation, even when the entire group plays loud and chaotically. Finally, therapists usually closely monitor their patients' choices of instruments as they often reflect the role they will tend to give themselves in a group, and choosing among many different instruments obviously means much more than simply choosing between only shaker and cymbal.

For all these reasons, a large and diverse palette of instruments is highly desirable, if not necessary. Thus, music therapists most of the time have one of two things: one or two places where they carry out the majority of their sessions and can store their gear, or a big van. But in addition to being difficult to carry, their collection of instruments often contains expensive, fragile pieces which cannot be entrusted to a child or a violent client. Therefore, any means of reducing the weight and cost of the instrumentarium should be pursued to make it easier for therapists to deliver music therapy to anyone who needs it, no matter where they are or what their issues might be. In particular, using a fully integrated system based on low-cost video game devices as an alternative to a classical instrumentarium will hopefully allow fitting music therapy in the often very tight budgets of most healthcare institutions, especially since compact, usable gear could easily be shared among therapists working in the same structures.

1.2.2 Blending Smoothly with Existing Protocols

In most clinical settings, the entire staff operates following extensively detailed procedures covering just about every aspect of their work. Of course, various down-to-earth problems, the most prominent being critical understaffing, often force healthcare workers to ignore some of these rules, usually without any dire consequences. However those procedures remain necessary, if only to cover institutions from facing undue legal actions when incidents occur.

Because of this very rigid and demanding environment, it is extremely hard for even the most motivated staff to introduce new methods or new tools. Therefore, the games we design must rely on safe, robust and easily available hardware since no one will have the will and time to set up and maintain complex systems which might pose too many threats to schedules and safety. Moreover, they must be extremely simple to use so as to keep the amount of training required from the staff as low as possible, since they have so little time to spare. Finally, they must not interfere with routine procedures; they will for instance have to be very quick to set up and put away, as safety concerns and lack of available space will likely forbid leaving the hardware out when it is not in use.

This calls for systems that use very few different devices, with as many wireless connections as possible to reduce clutter and no rare or custom parts to ensure easy maintenance. Furthermore, any new version will have to be thoroughly tested in a real clinical setup before release. Firstly, this will ensure that potentially harmful features can be detected and corrected or removed quickly. Secondly, the robustness demanded from clinical tools is much higher than for usual household appliances, as both patients and staff will become frustrated extremely quickly if things do not work right away. Thus, extensive testing with a wide variety of users and contexts will be necessary to find and fix as many bugs as possible. Lastly, it seems likely that many usability problems will stem not from bad design in a general sense but from the very specific characteristics of clinical environments, making these issues extremely hard to detect, let alone predict, without extensive testing in a real clinical situation.

1.2.3 Adapting to Each Patient

Several studies dealing with the Placebo effect [47] or hypnosis as medical tool [48] have shown that the couplings between psychology and physiology can be surprisingly powerful. Both dimensions should therefore be taken into account in any treatment method. However, it seems obvious that most of the benefits from music therapy will come from its effects on the psychological side. For example, playing any kind of instrument certainly does improve hearing, attention or motor coordination, as extensive research done on musicians has shown [4]. However, while functional rehabilitation therapy will focus on the specific movements and cognitive processes that have been altered, music therapy will have a much more general effect on patients. Playing may partly re-train or even restore the abilities they have lost, but this improvement will only be a byproduct, albeit a very desirable one, as the production of music will remain their main goal during the sessions.

Having such a prominent psychological resonance makes music therapy very sensitive to a patient's personal characteristics. Indeed, while a molecule effective against a given pathology in one individual will often work on many of those who share the same illness, people have extremely different reactions when it comes to music. In [49], E. Lecourt explains that several attempts have been made, mostly during the 1970's, to find which type of music would be best suited to treat a range of given afflictions such as anxiety or depression. However, this approach failed as it became clear that the same piece of music could have opposite effects on two different patients, even if they suffered from the same pathology. She cites the example of a man who suffered from severe anxiety and sought treatment through receptive music therapy sessions. After trying various relaxing musical styles such as Indian meditative pieces, she discovered that she was able to calm her patient by playing military marches. The very energetic, driving 2/2 beat of these pieces, which would unnerve most listeners with its repetitive patterns and aggressive accents, gave the patient a feeling of solidity and predictability which helped calm his anxiety.

This kind of example shows that it is crucial for music therapy techniques to be flexible enough to adapt to a patient's *sonorous history*. This is why music therapists who use active techniques always have such a big instrumentarium, which usually includes instruments made specifically for this context. For instance, they often use xylophones with only the bars corresponding to the C major scale, as normal, chromatic xylophones would be much too hard to play. However, these music therapy instruments, although they are simplified versions of normal instruments, often cost a lot more than their usual counterparts as they are made in much smaller numbers.

A music therapy computer system would allow music therapists to use any kind of sound that may fit their patients with very little effort, since it has now become possible to download high-quality, free-to-use sample sets of virtually any instrument from the internet [50]. This could dramatically improve the effects of music therapy on some patients, as previous works have shown that sometimes the introduction of a single new instrument capable of producing what Lecourt calls a *ferryman sound*[2] [51] can be the tipping point of an entire long-term treatment, creating a new bond with the therapist which can then be built on towards significant improvement, sometimes with striking ease. Moreover, again thanks to our approach using simple hardware and open software, the system could also easily be adapted to satisfy the needs of patients with various motor and cognitive capabilities. Instead of having to build or buy specific instruments, therapists could simply modify the software to get the behavior they wanted. With a little time and the right tools, it would even become possible for patients to create their own instrument, opening up a completely new treatment method which could for example be based on the design by each participant of his or her *avatar instrument*, very much like the avatars used in current massively multiplayer online games such as *World of Warcraft* [52].

[2] *Son passeur* in French

1.3 Data Collection for Evidence-Based Therapy

The introduction of numerous new measuring techniques in the medical world during the last thirty years such as magnetic resonance imaging has given birth to many new treatment protocols relying heavily on quantitative results. Qualitative assessment methods, which are very dependent on a physician's knowledge and experience, are still the norm but are more and more often complemented with quantitative tests which are not as sophisticated but much less subject to bias. Introducing a relevant quantitative assessment of the productions of music therapy patients has proven a very difficult challenge, but new tools such as those we want to design might be able to change that. Computers can record and analyze much more than the mere sounds produced and we think that analyzing the entire interaction data (movements, button presses, midi messages etc.) in addition to the raw sound could yield interesting results for research, diagnosis and treatment purposes alike.

1.3.1 Establishing Music Therapy

Despite the fact that it is one of the oldest medical techniques in use as of today [53], music therapy, according to us, does not yet enjoy the popularity it deserves. The main reason for this is that it is extremely difficult to perform solid quantitative studies in music therapy as the outcome to be analyzed, whether it is musical sounds or modifications in behavior and psychological state, is very hard to condense into figures. Consequently, new tools that collect new types of information through HCI (Human Computer Interface) devices or sensors are very much needed to finally establish music therapy as a legitimate secondary of even primary treatment method.

As was said earlier, the ability to record movement data, for example, could shed light on the actual effects of music therapy and provide a quantitative assessment of its benefits on patients. Instead of relying on semi-qualitative scales, which are always criticized as being too sensitive to the reporting physician's interpretations and biases, new studies could rely on the statistical analysis of large datasets of movement and interaction logs that only a computer can handle. Such results would be much harder to criticize and would hopefully turn the most skeptical of medical practitioners around.

This aim of establishing music therapy on solid medical ground is central to our approach, as having low-cost, easy-to-use music therapy systems remains pointless if they are only used by those who do believe in music therapy and would already pay for more complex, more expensive systems with more features. We hope that using computers to make research easier and widen its scope will finally yield the quantitative results that are needed to truly gain healthcare professionals' and the public's trust.

1.3.2 Screening and Monitoring Patients

We have explained how music therapy has to be very flexible compared to other techniques because it needs to adapt to each patient's tastes, feelings and cultural background. Indeed, a single person's emotional response to various types of music is so deeply unpredictable that even the most experienced music therapists still work with a lot of trial and error. More generally, it is usually rather difficult to tell whether music therapy will suit a given patient. Far more than drug-based methods, this type of treatment will exhibit a very variable outcome, working wonders for some patients and utterly failing with others.

Music therapists have acknowledged this phenomenon long ago and developed several tests to screen potential patients. The *Psycho-Musical Assessment*, designed by J. Verdeau-Paillès [54], is a musical analog of the Rorschach test [55]. It gives the therapist an idea of how defensive a patient is towards music in general, and consequently how useful music therapy may be, with hints of the types of music that might be worth trying with him or her. However, this test mainly applies to receptive music therapy and, more importantly, takes a long time to perform as several pieces of music have to be played and discussed.

Analyzing the data collected during a patient's first few trials of a music therapy system could be a good way to automate this kind of screening. The performance on a given musical task, such as following a rhythm, identifying a melody or playing along with a song could, with proper scoring, give useful indications on a patient's sensitivity to music. Moreover, if such a test proves feasible and efficient, it could be used as an assessment tool throughout the treatment. Therapists would then have an objective measure of their patients' progress. This would enable them to pinpoint exactly which kind of intervention is useful for each patient, as they often try different approaches but rarely can quantify their effects precisely enough and must still rely mostly on their intuition.

1.3.3 Assisted Diagnosis

Music therapy systems might even be able to go beyond simple screening and monitoring to help with actual diagnosis. Of course, scores on a video game of any kind will most likely never be reliable enough to decide on a treatment. They will always have to be reviewed and complemented with qualitative assessments performed by an experienced physician. However, we think that many tedious tests unrelated to music therapy could be embedded in a music game.

Diagnoses often involve performing long, boring or even painful tasks, filling out questionnaires and forms etc. But the more reluctant a patient is, the less accurate the results are. If patients were instead simply asked to play a game, they could more easily be kept focused long enough for the results of the test to be significant. Of course, any sort of game could be used in this kind of situation, but we think that given its universality, music would be a very good basis for this type of approach. Indeed, a test game has to appeal to all types of patients, since it would otherwise be too biased, with the more motivated patients performing much better. We hope that the body of results that music therapy systems such as ours yield will someday give birth to such a game, although it is of course a long-term perspective as many much more simple and down-to-earth issues such as total accessibility have yet to be solved.

Chapter 2

Related Work

As far as we know, computer music, healthcare, game mechanics and off-the-shelf gaming devices have never been mixed together into a single system, although several initiatives such as *MIDICreator* [56], *SoundBeam* [57] and, more recently, *GenVirtual* [58] have approached this idea. However, many people have combined some of those dimensions to build a wide range of systems from which we drew inspiration. We review these works in order to discover potential keys for a musical serious game's success and, even more importantly, identify the many caveats it must avoid to gain widespread acceptance.

2.1 Music Therapy Tools

In a 2007 article [39], E. Streeter tries to explain how and why the music therapy community is so slow at incorporating electronic and computer music technologies, even though they have been used by adventurous musicians for more than 40 years. In the beginning those technologies were very expensive and complicated to use, but one can safely say that by 1990 powerful, affordable hardware such as the *Atari ST* made composing and playing music with a computer easy enough for any slightly motivated musician to experiment with [59]. Nevertheless, more than 20 years later, music therapists still very rarely take advantage of the musical capabilities of computers, even though they have become far more versatile and far cheaper than the ST in its time. Here, we review those of the numerous attempts at digitizing music therapy that, according to us, had good potential. We explain what we want to keep from them and why, but most importantly try to figure out what prevented these otherwise very promising systems from becoming more widely used in therapeutic settings in order to design tools that will finally make it to hospitals and therapists' offices.

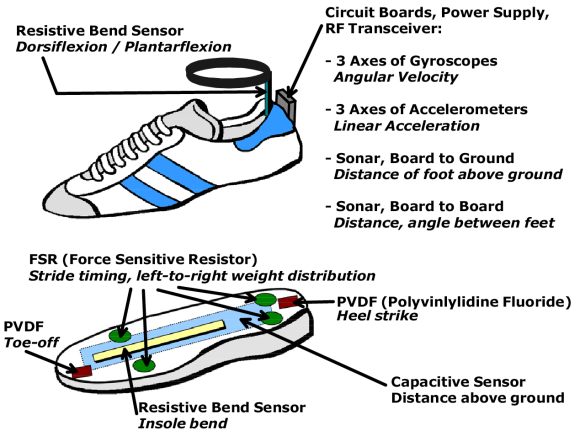

Figure 2.1: Instrumented Footware sensors.

2.1.1 Music and Movement

A fairly common but very interesting idea explored at MIT was to use music as an alternative sensory feedback. Using their *Instrumented Footwear* [60], researchers aimed at helping patients suffering from walking problems, for example as a consequence of Parkinson's disease, to compensate for their deficiencies and learn to walk again. In order to do so, they designed a pair of shoes rigged with sensors: accelerometers, gyroscopes, pressure sensors and so on (see Figure 2.1). This enabled them to detect a wide variety of issues in the dysfunctional walking patterns of their test subjects such as shaking, improper weight balance between the two feet, irregular pace or even bad posture.

The trick was to give patients an auditory image of their walking, for example linking balance issues to left-right spatialization, shaking and trembling to added noise levels or irregular pace to erratic tempo changes. As music has been shown to be able to restore fine motor coordination skills to a surprising degree, enabling Parkinson patients to dance although they were barely able to walk [4], using music as a dynamic guide for walking rehabilitation seems like a very good idea. Here, musical feedback plays the same role as the therapist in a traditional setting, which is to inform patients about what is wrong with their walking pattern and encourage them to correct it. However this novel approach seems much more fun and motivating and therefore very well illustrates the type of work we intend to do: take a classical method and infuse it with music and fun in order to enhance it without changing the core procedure.

It is easy to guess that all this custom hardware comes at a high cost and is not very easy to set up, which is most likely why this system was, to our knowledge, never used in a real clinical setting. But it is worth noting that this research already dates back quite a while; the system could probably be implemented again for a fraction of the original budget using today's video game technology such as Wiimotes and Wii Balance Boards.

With similar goals but a different approach, researchers from the University of Sao Paulo designed an augmented reality system and evaluated it for cerebral palsy treatment through music therapy [61]. With *GenVirtual*, the therapist can use a deck of printable cards of different sizes that each represent a note with the timbre of a given instrument. By carefully arranging the cards in front of the patient, he or she can have him or her play the melody of his or her choice with exactly the desired movement pattern.

The goals here are the same as with the Instrumented Footwear. The classical rehabilitation procedure, which consists in designating various points on a table and having the patient touch them in a given order, is augmented with a fun and motivating dimension through the use of music. However this approach is also radically different in the sense that here music is simply a motivator and does not act as a carrier for sensory feedback. But in contrast with the *Instrumented Footwear*, this system is much less costly and much easier to set up as it only requires a computer, a webcam and a printer. This should make it much easier for this system to reach a wide audience than for MIT's augmented shoe as most music therapists will already have the necessary hardware at hand. Since large-scale diffusion is also one of our goals, we plan to approach the issue the same way and use easily available hardware exclusively.

2.1.2 Digital Music Therapy Instruments

The University of York (UK) is very active in the field of digital music therapy. They have released two very interesting designs which use computer technology to create musical instruments specifically tailored for music therapy. Much like the variations on traditional instruments manufactured for this purpose, said computerized instruments' goal is to allow non-musicians to express themselves through music. This means that they are supposed to be more intuitive to manipulate and require less training than regular instruments.

Emphasizing ease of use like this always has to be done at the expense of musical freedom, as being able to generate a wide variety of sounds and patterns is precisely why modern instruments are so complex to handle. For example, while a normal vibraphone has its bars arranged like a piano and can play chromatically, music therapy vibes only have the bars corresponding to a single scale, usually C Major. This means that, in contrast with a regular one, a music therapy vibes can only produce notes that go well together as they all belong to the same scale, which is we one wants for most music therapy sessions. However this greatly limits its musical versatility, since it will for example not be able to play anything nice in certain keys such as C#.

The main goal of digital music therapy instruments is to achieve a satisfying degree of intuitiveness and ease of use while retaining as much musical expressiveness as possible, especially in terms of timbre, as patients are usually less interested in making complex patterns than in exploring different sounds. MIDIGrid [56] aims to give even the most disabled patients access to interesting sounds and patterns with just one hand. It works in a very simple way: the patient's computer displays an array of cells, each of which has been filled with a specific timbre-pattern combination chosen by the therapist. Simply by clicking the cells, players can then produce fairly complicated combinations of sounds. Moreover, if the system is synchronized with an external pulse, it becomes very easy to make music with proper rhythm, using MIDIGrid like a loop machine.

Of course this design is very simple, but making things complicated does not necessarily help. Here, patients easily understand what the interface does and can operate it with just one hand. This is more than enough for most, who are very happy to explore the already very wide variety of sounds that can be generated, which far exceeds what can be achieved with the single cymbal or shaker that patients are often given during classical music therapy sessions. We intend to follow this approach and keep things very simple when we make our games. Indeed, the success of this previous application shows that even very straightforward interfaces which do not allow for much expressiveness can already satisfy most patients.

MIDICreator [56], on the other hand, is a far more ambitious project. The goal of this software platform is to enable creative instrument makers to hook up various kinds of sensors such as accelerometers, pressure sensors or even thermometers to a computer music system and generate sounds and images according to the signals they produce. This makes it possible to augment regular instruments with new sounds and video capabilities, something the researchers have demonstrated with an augmented drum. Moreover, it gives the ability to create completely new, intriguing instrument designs such as those featured in the MIDICreator-based sonorous playground installed at Lidgett Grove School (UK) (see Figure 2.2).

Experiments with MIDICreator have shown that creating sounds with movements and interactive objects which look nothing like musical instruments can be a lot of fun for children. These instruments of a new genre would have their place in a music therapy setting as they allow for intuitive control of virtually any sound. However this system, in its industrial version [62], costs about $2000, which is most likely the reason why it does not seem to have reached a very wide audience in spite of promising capabilities. Consequently, while this experiment shows that motion-controlled computer music is a viable option for music therapy, it also greatly stresses the need to design very easily deployable systems, as we do want our games to be used by as many patients as possible.

SoundBeam (see Figure 2.3) partly avoids the deployment issues of MIDI-

Figure 2.2: MIDICreator-based sonorous playground.

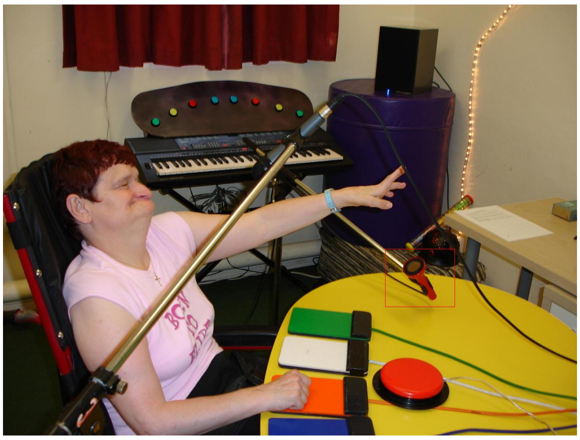

Figure 2.3: SoundBeam system and accessories.

Creator as it easy to setup even for people who know very little about computers. It uses an ultrasonic beam akin to that of a medical ultrasonograph to sense the distance between the source and the players hand; this distance is then used as an input parameter to pilot a virtual synthesizer running on an attached computer. As far as we know, SoundBeam is the most widespread special instrument in the music therapy community, as it is used in more than 1000 institutions in 20 countries, and seems to be very popular with patients and therapists alike [57].

That being said, none of the music therapists we met in France knew about this device, which means that it still has quite a long way to go in terms of diffusion. This is likely due to its high price, at least $3000 for a one-sensor system, which is roughly three times as much as the absolute maximum of $1000, computer and audio-video system included, that we envision for our systems. However that does not mean that SoundBeam is not worth its price, as it rates very high in terms of expressiveness and

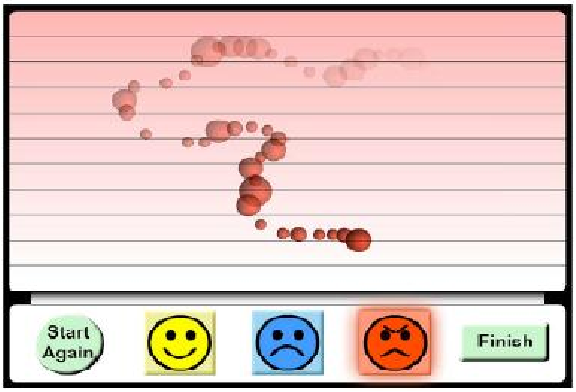

Figure 2.4: The main screen for Riley's tool.

accessibility at the same time, while being easy to setup, which is quite an achievement.

The last tool we are going to examine is again from the UK, but this time from Dundee University [63]. It is geared towards demented patients with a moderate impairment at most and focuses on musical creativity. Patients are invited to choose between "happy", "sad" or "angry" styles, which respectively correspond to major, minor and minor/major chords and are represented by clickable faces on screen, and create music by tapping and sliding their fingers on a touch-sensitive surface divided into a scale (see Figure 2.4).

The demented patients who tried this system really enjoyed the experience, according to the user feedback reported in [63]. They were able to play pleasing music with the interface, which guarantees consonance by using a single scale, just like a music therapy vibes. Moreover, the recent explosion of the tablet market is bound to finally drive the cost of large touch-sensitive displays to a level low enough to become truly accessible to casual users, which should make Riley's application easy to deploy and diffuse. However, it seems that while the application was at first designed for autonomous use, demented patients' executive difficulties rendered them incapable of improvising without constant prompting. This is a strong hint that the design of our own applications should be designed with the caregiver in mind from the start, as his or her presence is likely to be necessary no matter what we do.

2.1.3 Session Management and Analysis Tools

Music therapists spend a very large amount of time listening to and analyzing the recordings of their sessions. This helps them track their patients' evolution throughout the treatment and often enables them to discover meaningful features and relationships which they did not notice on the spot. However the clues they obtain this way, even if they are useful, are rarely truly worth the effort. Consequently, only dedicated researchers will usually carefully listen to everything they record. Everyday therapists just archive the recordings and only take them out if they have an intuition or want to verify something. For this reason, researchers from the University of Jyvaskila have tried to design computer algorithms that would analyze music therapy sessions automatically and give therapists hints about what parts they should listen to and what they might find in them.

The Music Therapy Tool Box (MTTB) [64] is a set of MATLAB routines which take in the MIDI recordings of a musical dialog between two people, i.e. therapist and patient, and computes various features such as note density, mean volume, tonal center etc., some of which have been shown to be closely correlated with clinically significant parameters such as patients' level of mental retardation or simply their degree of implication in the improvisation. One could imagine using the latter to indicate which parts should be the most interesting to listen to, since it seems likely that a portion where patients play automatically without paying any attention would not carry as much information for the therapist as those moments where they are in a state of flow.

Unsurprisingly, the MTTB can only operate on MIDI files, which are far easier to analyze than traditional recordings, if only because they store what each player has produced on separate tracks. This multi-track representation would be extremely hard if at all possible to reconstruct from a normal stereo recording [65] and would consequently require using multiple microphones, which is totally impractical in a clinical setting. Using digitized musical instruments that communicate with the MIDI protocol consequently seems like a natural solution to this problem.

Another thing that computers are good at is recording large quantities of information automatically. That is the point of the Music Therapy Log-Book, a custom recording system currently being tested by E. Streeter who has not yet published her results. It aims at simplifying the management of sessions by collecting relevant data without the therapist's intervention. It automatically computes various statistics such as playing time, number of participations, tendencies in instrument choices etc. as well as a cross-correlogram between therapist and patient which can indicate when one is following the other.

All this data is very interesting for therapists as it can indicate trends in a patient's evolution. For example someone whose playing time increases throughout the treatment is most likely taking interest and developing a trusting relationship with the therapist. Although this is nothing extraordinary, having this kind of data available will enable music therapists to support their claims with numerical evidence and at the same time give them more freedom to focus on their patients by automating some cumbersome tasks such as keeping track of session dates and lengths or instrument choices. We hope that by including these features in our applications, maybe simply by making them compatible with the Music Therapy Logbook, we will contribute to the spread of evidence-based music therapy.

2.2 Music Games

Music has always been given a lot of attention in the gaming industry. Rhythm games such as *Parapa the Rapper* [66] or *Dance Dance Revolution* [37] have generated a lot of interest from the community and proved very profitable. However the enthusiasm of the public for music games recently reached unprecedented heights, with a large number of games following in the footsteps of the iconic, all-time best-seller of the genre: *Guitar Hero* [35].

2.2.1 Challenge Games

Music games have thrived these past few years, mainly thanks to the new control interfaces that are now available to the public at an affordable price. *Guitar Hero* and *Rock Band* [67] use specific devices that can be seen as simplified and stylized versions of a guitar, drum set, etc. The gameplay is very straightforward: some kind of musical score scrolls through the screen and the player is ranked on his or her ability to execute the required synchronized presses, strokes etc. with adequate timing. Similarly, games like *Singstar* [68] or *Karaoke Revolution* [69] give the players a series of notes to sing in a USB microphone. The accuracy of the players in terms of pitch and rhythm is then scored by comparison with the original version. All these games leave very little room for improvisation, which is much harder to score reliably, but they do reserve a little space for unscripted bonus actions and flourishes which give players an occasion to forge their own style.

These games put emphasis not on gameplay but on making the player feel like he or she is a true virtuoso rock musician. Their enormous commercial success clearly shows that complex game mechanics is not necessary to motivate players, since things such as hard challenge and strong evocative power can be sufficient. The former is created through the progressive unlocking of increasingly intricate and fast songs and reinforced by the constant encouragements players get from the game. The later is supported by high quality graphics and soundtracks but, most importantly, by the use of instrument-like gaming interfaces. Even though they have no more capabilities than a classical gamepad, except of course for the microphones, they contribute greatly to player immersion by suggesting gestures analogous to those of a real musician.

2.2.2 Improvisational Games

With a rather different approach, Wii Music [70] invites the player to try different instrument types, each with its specific Wiimote control gestures. The game puts much more emphasis on experimentation and improvisation.

Though such a sandbox approach may not work with teenagers thrilled by challenge, as shown by comments on various video game websites, younger children and older, casual or even non-gamers are much more interested in this kind of gameplay. However there is a big trade-off here between freedom of playing and musical quality: it seems very hard to design a game that both gives players improvisational freedom and ensures that music nice enough not to scare those around is still going to come out. That is why players state in some of the comments that they did not feel in control of the music, since with certain playing modes they could not do anything more than modify the tempo of the music by swinging their Wiimote.

Similar results were obtained with Pads'n'Swing [71], a serious game where the underlying motto was jazz improvisation teaching. The idea was to encourage players to improvise in a jazzy way by freeing them from the technical barriers they would encounter with real instruments through the use of a gamepad as a simplified musical interface. However, in order to give players some hints about what could be played, Guitar Hero-like musical scores were also introduced. The whole point of the game was to improvise with the suggested notes as a basis, but most younger players, craving for challenge, simply ended up trying to maximize their score by hitting each and every proposed note, forgetting improvisation completely. This clearly shows the tension between challenge and freedom, and demonstrates that, if melodies are to be suggested in order to seed improvisation, they must remain very simple, even somewhat boring, and have only a minimal impact on the score. Otherwise players will retreat to a basic, challenge-based playing in which they feel much more secure than when they are given complete improvisational freedom.

2.3 Games in a Healthcare Environment

Long before the first health-oriented games were released, precursors in the healthcare community started using regular, commercial games in a therapeutic setting. Here, we describe a few key examples that are related to what we intend to do in terms of context of application, interface or gameplay design practices.

2.3.1 Games for Psychodynamic Therapy

In his various papers (see [72] for an example), Michael Stora describes how he uses several carefully chosen off-the-shelf video games as support for his work with children in analytical psychotherapy. He has shown that video games with strong narrative content such as *Fable* [73] or *Ico* [74] can be very efficient and compelling mediation objects for children who have difficulties to talk about their suffering. It enables them to symbolically dive back into the traumatic situations that caused their trouble and learn to deal with them in a reassuring setting with the therapist's help.

More specifically, because video games are interactive, they are more likely to make the children reflect on the story they are playing through than if they were reading a book or watching a movie. Players, contrarily to viewers or readers, are forced to make choices and must consequently thoroughly consider the possible outcomes from a practical as well as a moral point of view. Games therefore constitute a very good medium for therapy, as the tragic situations they expose, such as treason, abandonment or loneliness, are most of the time canonical enough for the children to easily relate to and elaborate on, giving precious clues about their inner workings to the therapist listening to them.

2.3.2 Wiimote Games for Healthcare

In work that has yet to be published, but has received extensive media coverage, Kahol and Smith [75] study the benefits for surgeons of playing *Marble Mania* [76] on the Wii. The fine motor skills that are put to the test in the game (Wiimote pitch and roll control) are, according to them, very similar to those required to perform clean and efficient surgery. Results suggest that surgeons playing one hour of *Marble Mania* a day perform 48% better than those who do not. This means that the Wiimote is sensitive and precise enough to qualify as a complement to, or maybe even as a replacement of, medical simulators which often cost tens of thousands of dollars. Consequently, if it is good enough to train surgeons, it should also be sufficient to make expressive music instruments for non-musicians.

Besides surgeons, many patients suffering from a wide range of illnesses already benefit from the Wii. There are the numerous elderly residents of nursing homes who now play games like *Wii Bowling* or *Wii Tennis* with great pleasure, as they are fun, intuitive and encourage interaction with other residents without requiring a lot of effort, as only simple, small movements are necessary to play. But beyond simple fun, these games are also used in rehabilitation centers where patients suffering from functional disabilities resulting from a stroke or heavy surgery can practice painful movements in a much more motivating context, leading to more intense focus and thus to quicker recovery.

2.3.3 Exergaming

WiiFit [25] provides a new and fun way to exercise by offering players various games that are played with the Wii Balance Board. These are divided into four categories: strength training, aerobics, yoga and balance games. Besides raising awareness on the dangers of doing too little exercise, *WiiFit* is what is often called an exergame. The gameplay is what is truly beneficial: playing is fun but requires an effort and the automatic scoring and tracking through time motivates the player to exercise every day. Along the same lines, games such as *Your Shape: Fitness Evolved* [77] make use of the soon-to-come Kinect [34] controller-less interface by Microsoft to track a player's fitness movements and provide feedback on precision and speed, thus motivating him or her to persevere and perform better.

However exergaming is not solely for the body. Games such as *Dr. Kawashima's Brain Exercise* [78] claim to strengthen one's brain through cognitive training such as memory games, sudoku, attention games etc. Although the therapeutic efficacy of this particular game remains unproven, several studies suggest that exercise for the brain does indeed enhance or help preserve its capabilities [79]. These works and the tremendous success of *Dr. Kawashima's Brain Exercise* encourage developers to release this kind of game and many believe that one of them will soon be rigorously shown to have a measurable impact on cognitive performance.

2.4 Serious Games for Health

As serious games developed, healthcare increasingly appeared as a field with a lot of potential applications. The first Games for Health conference, supported by the Serious Games Initiative, was held in 2004 and the event has grown bigger every year since then. The field has now reached a certain degree of maturity, with the success of very large and costly projects such as Pulse!! [26], a game targeted towards medical students. An exhaustive review of all the major initiatives in healthcare gaming would be far too long for this thesis, so we will focus on a few characteristic examples which will serve to illustrate and justify our design choices.

2.4.1 Therapeutic Gameplay

The number of patients in need for functional reeducation is higher than ever, most notably due to a significant increase in survival rates for strokes and accidents in general. However, although efficient if carried out properly, rehabilitation is a tedious process that often fails because patients drop treatment. This is a textbook case for the application of serious gaming techniques, as shown by the ongoing Rehab Games project at the University of Skövde [44]. For example, a simple interface with pull ropes, very much like a rowing machine, was designed for upper body rehabilitation. From a motor point of view, patients exercise just the same as they usually do. But a gaming layer is superimposed on this process: depending on what game he or she chooses, the patient's movements may result in bad guys getting punched, a bike steered out of danger etc. As with *WiiFit*, rehabilitation becomes much more fun and patients therefore commit to the treatment more willingly.

Another kind of therapeutic gameplay was developed by Smart Brain Technologies using a brain-sensing helmet originally created by NASA in order to enhance its pilots' attention skills [80]. The *SmartBrain* system connects to a regular PS2 gaming console and adds a neurofeedback component to existing games. For instance, in the racing game *Burnout* [81], the system monitors attention and modulates top speed accordingly. The player, for example a child with Attention Deficit Hyperactivity Disorder (ADHD), will only be able to accelerate to full speed if he or she is focused enough. If, on the contrary, he or she lets distractions divert his or her attention, the car's maximum speed will be throttled down, making it impossible to win the game. This once again illustrates the power of the new biofeedback computer interfaces that are spreading nowadays as they can turn a very basic gameplay, here racing, into a powerful yet fun therapeutic system.

2.4.2 Motivation-centered Gameplay

One rather straightforward way of applying serious gaming techniques to the world of healthcare is to design games that, without being therapeutic themselves, motivate the user to follow a given treatment. The Bayer *DIDGET* glucose meter and dedicated game work like this for children with diabetes [82]. The idea is to award children with points for regularly testing themselves, with bonus points awarded for meeting the target glucose levels specified by their therapist. These points can be used to perform special moves, buy necessary equipment etc. and therefore are an integral part of the gameplay. This turns the formerly boring and tedious task of taking and analyzing blood samples into a fun activity, giving children immediate reward for their efforts instead of the unclear, rarely understood and therefore rather uneffective motivation of preserving their health.

Similarly, Michael Stora is currently working on a game, untitled as of today, which should help overweight kids with their diet. The goal is to work together with parents to have kids play a game where their efforts award them energy points necessary to progress through the story. Furthermore, an online mode should be included where children can put their hard-earned points in common with their peers in order to complete team challenges. Michael Stora hopes that this specific feature will be especially effective, giving birth to a new form of game-mediated group therapy for obesity. However one must be careful when confronting children like this: even if they all share the same problems, seeing that others are progressing while he or she is not can be devastating for a kid. For that reason, one must ensure that no negative feedback is ever given and that it is effort and not success that is rewarded. Consequently, just like *DIDGET* points are awarded simply for testing oneself, with glucose level points being only a bonus, diet points will be awarded as long as kids more or less follow the diet prescribed by their physician.

We think this failure-free approach is crucial and constitutes a specific characteristic of healthcare games. Indeed, while normal games rely on challenge as a motivational tool, healthcare games cannot take the risk of frustrating players and deterring them from their treatment. Therefore, designers have to find a proper balance between challenge and instant pleasure, but most importantly reward effort as much as possible, so that players always get a positive feedback from the game even if they have very poor gaming skills.

2.4.3 Learning Games

Re-mission [41] intends to improve treatment acceptance in children undergoing chemotherapy. It takes the form of a third person shooter game where the player has to wander in a child's body and destroy cancerous cells. Throughout the game the player visits various body parts and learns about the disease and how the treatment works. Playing Remission has been shown to improve the children's knowledge and self-esteem, which in turn leads to better commitment to the treatment. This is very important as chemotherapy can be very tough, with nausea, extreme fatigue and dizziness being very common. Motivated children suffer less from these side-effects and therefore can take on more potent, longer treatments, thereby increasing their chances of survival. As the term learning game indicates, what is beneficial here is the knowledge gained by the player. The gameplay in itself is absolutely standard and only serves as a catalyst.

Some games like LudoMedic [83], even though they use the same basic strategy of encouraging learning to reduce anxiety and side-effects, go beyond this pathology-centered design to present kids and parents with a complete walkthrough of their treatment. Here, children take control of an avatar who will go through multiple adventures in a hospital. The objects and characters they encounter are stylized with a manga feel that appeals to kids but remain faithful enough to reality to be easily recognized in real life. What is truly interesting here is the approach followed by the developer, CCCP. Instead of building a monolithic game, they created a fully functional game engine and level editor which enables them to easily add specific content commissioned by one of their partners or asked for by practitioners. The simplicity of the level editor makes it possible for physicians to participate in the design of the adventure, which ensures faithfulness and helps build a community around the game as practitioners directly involved in the design process are much more likely to advocate its use. Additionally, kids and parents who want more information are re-directed towards the game's website and Facebook page, where they can share their thoughts and find support. We think that building a community around our games like this is very important for them to evolve without us. Thus, we will set up a comparable web platform that will make it easy for patients, caregivers, developers etc. to interact and share their tips.

Chapter 3

Key Design and Methodological Choices

The goal of our work is to specify a proper framework for making musical serious games for health. To this end, in Chapter 1, we outlined the multiple objectives we intended to pursue by making our own blend of music therapy and video games. Here, we describe the key design and methodological choices that embody these objectives: we rely on Wiimotes and free software to lower cost and ease deployment, game design practices and Action Research to ease and optimize the design process, and data analysis to validate our approach from a therapeutic point of view. These are the defining characteristics of our framework; they serve as a basis for a first meeting with healthcare practitioners when we decide to make a new game.

3.1 Wiimotes

One could rather easily argue that the Wii's revolutionary motion-sensing controller, the Wiimote (see Figure 3.1 was the key to the Wii's success. This is somewhat surprising, since its components are neither the newest nor the best from a technological point of view and it is therefore not at all precise enough to give designers a realistic one-to-one motion sensing tool, which was a great disappointment for many Nintendo fans. However, its success with all kinds of gamers clearly proves that it is good enough to enable creators to add a relevant new dimension to their games; we think it can do the same for music therapy.

3.1.1 Low-Cost, Feature-Rich Controller

The Nintendo Wiimote is designed to be held in one hand. It features:

- 5 buttons on the top face.

Figure 3.1: The Nintendo Wiimote.

- A direction cross, also on the top face.
- A trigger on the bottom face.
- 3 orthogonal accelerometers.
- A high-speed infra-red camera.
- A speaker.
- A vibration unit.
- A Bluetooth transmitter.

Moreover, the Wiimote can be augmented with accessories that plug into the extension port on its back. That represents quite a lot of hardware packed in a small space but Nintendo has nevertheless managed to maintain the price of its controller below the $50 bar.

Prices were kept in check by using not-so-new components and producing on a very large scale, so much so in fact that it can often be cheaper to buy a Wiimote than an equivalent wireless accelerometer or camera. But this by no means implies that Nintendo's device is not a capable controller. Games like *Marble Mania* (See Chapter 2) have shown that the accelerometers are sensitive enough to implement a gameplay which actually improves the fine motor skills of surgeons; a tool that works for surgeons should work for music therapy patients if it is used properly. Moreover, the pointing system, which relies on the camera and two IR diodes placed above the screen, makes it

Figure 3.2: The Wiimote Pistol.

possible to comfortably pilot a computer from a distance if proper filtering algorithms are implemented to reduce jitter. Therefore, it should also be sufficient for patients to play our games, which will hopefully be far less complex to handle than the day-to-day use of a computer.

The small weight and size of the Wiimote make it suitable for use by almost anyone, from small children to mobility-challenged elderly people. With its numerous features and robust technical characteristics, it should allow us to design many different kinds of games using a virtually infinite number of motion-based control schemes, all tailored to make things as intuitive as possible for our target audiences.

3.1.2 Commercial and Community-based Mods and Add-ons

One of the great advantages of using popular, low-end controllers instead of custom devices is that they usually can be customized and complemented with ready-to-use mods and add-ons. The success of the Wiimote, especially, has given birth to a very large market for multiple satellite products that add new features and allow for even more diverse control schemes. For example, the *Nunchuk*, which plugs into the extension port of the Wiimote, adds an analog joystick and three very precise accelerometers. Better yet, the *Wiimote Plus* contains a gyroscope which yields complete one-to-one motion sensing capabilities and allows for very precise control. Additionally, many other accessories exist that do not add any new features to the Wiimote but dramatically change its affordance for a given task. The *Wii Pistol* (see Figure 3.2 or the *Mario Kart Wheel*, for instance, are just plastic shells that do not contain any electronic components and therefore do not add any new capabilities. However they contribute greatly to the gameplay by giving the Wiimote a new shape which makes a given task, here shooting or steering, easier and more intuitive.

Additionally, the Wii is so revolutionary and so pervasive that it has sprouted a vibrant community of homebrew developers, whose goals are as diverse as running Linux on the Wii, controlling music synthesizers with a Wiimote, a practice called WiiJaying, or simply browsing the web and playing games from a distance on a PC (see [84], [85]). All this was made possible by the fact that Wiimotes use a standard Bluetooth protocol to communicate with the Wii. Once the actual meaning of the data transmitted had been reverse engineered, it became very easy to connect them to any Bluetooth-enabled computer. From then on, developers started to use the Wiimotes in new and creative ways, frequently producing algorithms and control schemes far better than those implemented by Nintendo. Some like Johnny Lee [86] even devised a way to use two Wiimotes as an inexpensive, wireless stereo IR camera to make a full-3D motion capture system for an extremely low price. Choosing this controller to build our systems and play our games lets us leverage all these participative efforts. This way, we can both limit the amount of technical work necessary to focus on design and get inspiration and advice from all those who have tackled issues similar to ours in making their own games.

It is however worth noting that even with these add-ons and custom algorithms, repeated errors in measurements add up to too much drift to fully locate the Wiimote in 3D space by relying only on proprioception. An exteroceptive 3D sensor such as a stereo camera needs to be added to the room to correct these errors about once per second. This limitation, and a few others, explain why the Wiimote is clearly not the ultimate gaming controller. What we intend to show is simply that it is good enough for a start. Of course, new music therapy games should be developed when better interfaces become widely available, but we think that they will still benefit a lot from the experience acquired with the Wiimote.

3.1.3 Affordance for Fun

Nintendo has built its success on innovative and meaningful designs that have made consoles like the DS [87] or games like *Mario Galaxy* [88] extremely popular. They provide new gameplay ideas and mechanisms that appeal to a very wide audience. It is true that Nintendo's primary targets are still children, as proven by their constant use of funny, super-deformed and brightly colored characters and environments. However, games like *Mario Galaxy* also greatly appeal to older gamers, even those who were rival Sega's *Sonic* fans in the old days, because they provide a truly innovative gaming experience. At first, players are often put off by the typically Japanese *kawaii*[1] visual universe and story as well as the simple-looking game mechanics, only

[1] The word *kawaii* is usually translated as cute. Although it is literally accurate, it misses out on the important cultural dimension that *kawaii* has gained, as it has come to designate a whole movement in Japanese popular culture which is increasingly embraced by the population as a part of the Japanese identity.

to be quickly conquered by Nintendo's extraordinary mastery of gameplay design.

The Wiimote is a very good example of this phenomenon. Its slick, white looks beautifully embody Nintendo's vision of gaming and fun. It does not have many buttons, but a majority of the games that come out do not even use all of them, so extra triggers, analog sticks etc. were considered unnecessary. Its accelerometers are not very precise, nor is its pointing system, and it does not have any gyroscopes at all. Therefore, many have justifiably argued that the Wiimote is a rather poor motion sensing device. But Nintendo has shown, with games like *Wii Bowling* [32], that just a few buttons and a rather unrealistic control through motion are sufficient to create a fun game, moreover one that appeals to an extremely wide audience with a great proportion of non-gamers.

We think that this focus on simplicity is a very important characteristic for serious games to be used in a healthcare environment. In hospital settings, patients are used to being surrounded by complex machines which are often somewhat intimidating. Giving them something that clearly contrasts with the usual design of medical appliances, which focus on functionality and often neglect aesthetics, should make it clear that the primary point of the proposed activity is just to have fun.

3.2 Free Software

Free software has two main defining characteristics: it is freely usable and freely modifiable. The first part is the simplest to explain. As the Free Software Foundation says [89], it means free as in *free beer*: anyone can download, use and distribute free software with very few restrictions which mainly pertain to intellectual property. The second part is more subtle. The GNU Foundation explains it by free as in *free speech*: free software has to be easily modifiable and customizable, which means that its source code has to be publicly available and that anyone can publish and distribute his or her own version of it. To us, this *free* approach should be seriously considered for any software product, in a business model of software as a service, but it is especially relevant in the healthcare world.

3.2.1 Low Deployment Costs

One of the downsides of free software is that it is usually not as easy to install and as user friendly as commercial products. Indeed, most of the time, applications focus more on features, simply because those who need them implement them for their own use at first and therefore care less about aesthetics and usability for others than commercial developers. Thus, using and especially developing free software often requires quite a lot of preparatory work to understand existing code, which, because it is created by only loosely connected individuals instead of an actual development team, is not always written with a consistent design and implementation strategy.

Nevertheless, thanks to institutions such as the Free Software Foundation or the W3C, growing standardization through public APIs and frameworks as well as multi-platform code makes development easier as time goes by. For example, many python libraries such as NumPy [90] have become the *de facto* standard for the purpose they serve, so that it becomes less difficult to link portions of code from different projects as they tend to use the same libraries. But despite the fact that they often re-use a lot of code from other free software projects, efforts like ours targeted at non-specialist end-users usually require quite a lot of work. First, the different parts borrowed from other projects have to be fitted together in a robust way, which is rarely easy, always time consuming and requires a lot of testing. Second, it is most of the time impossible to re-use a lot of the GUI part of the code, as this is usually very application-specific. For example, tools targeting visually impaired patients will often need to provide two GUIs: one for the caregiver, with all the menus and buttons needed to fully configure the software, and one for the patients with only the most important items so that text and images can be displayed as large as possible.

However development costs are not really an issue here, since we focus on simple applications that do not require too much initial work and are then given to the community. The real issue is cost of deployment and that is where our approach is much more efficient. Even government-funded software has to sell for a price if it uses commercial software libraries, as royalty fees often have to be paid according to the number of copies distributed. For large institutions, buying these licenses quickly becomes far too costly as software has to be installed and used on tens or even hundreds of different machines.

Obviously, free software completely alleviates that problem. Consequently, the deployment costs of applications such as the ones we intend to implement only include hardware and human resources. As the previous section explains, we address the hardware problem by relying exclusively on low-cost devices such as the Wiimote. In addition, we take a series of carefully thought out measures (see Sections 3.3 and 3.4) to make sure to obtain final products that are very easy to install and use in order to keep the human resource costs low as well. All this adds up to extremely slim deployment costs for the end users, which is without a doubt a prerequisite for penetrating hospitals and other healthcare institutions where budgets are always very tight.

3.2.2 Trust and Adaptability

Anyone who has worked at a hospital knows how complicated and rigid their IT infrastructures are. It is not the point of this thesis to discuss the possible causes and solutions for this but we do have to take this problem into account when we make our games. First, many different types of computers, operating systems and specialized devices cohabit, often not too peacefully, on the global network. IT teams are therefore often extremely reluctant to add anything new, be it hardware or software, for fear of breaking a fragile equilibrium.

One could argue that this is the same in most environments, but it takes a special importance in our case as patients' safety becomes more and more dependent on IT systems. Therefore, instead of proposing a frozen software solution, we choose to provide the source code to our programs as well as assistance in compiling them. This way, IT departments can easily adapt our software to their constraints, for example by disabling certain features. On the other hand, this also allows them to link the software to their own databases and application servers in whatever way they see appropriate to fit the local data policies, which for instance often require that a trace of all medical acts be kept in a secure place.

Moreover, releasing the source code of our application is one of the arguments we use to gain the trust not only of system administrators but also of physicians, staff and patients. First, this ensures that no malicious routines are included. In healthcare environments privacy is vital as leaks could have dire consequences for patients, be it regarding insurance costs, employment opportunities or simply family and social matters. We must therefore provide software as transparent as possible, with clear data policies, so as to show that no harm to privacy could come from using our tools. Secondly, releasing free, open-source software means that we do not intend to make money off the operation, which should give users the insurance that we have no purpose but to enhance everyone's quality of life with the help of the whole open-source community.

3.2.3 Community-driven Customization and Evolution

The open-source movement was more or less born with the first academic computers. University researchers released the source code of their algorithms and applications so that other teams in the world could replicate their results, which is the basis of peer reviewing. Then, the arrival of GNU/Linux systems and the globalization of the Internet in the 1990's gave the movement a large boost, as more and more people became able to use free software on the job or at home. However, it seems that the movement has had to wait for the arrival of Ubuntu, a very popular and user-friendly version of GNU/Linux, to really take off during the first decade of the 21^{st} century. A very large community of open-source developers now thrives and grows everyday and we hope to rally part of these people to help our tools evolve.

Of course, just like any other open-source application, we count on the community to provide additional testing and bug fixes. This is especially important since our software has to be extremely robust in order to really be put to use by healthcare practitioners. Nevertheless, this is something we could rather easily do ourselves; what is truly important is what the community could provide that we cannot. The first thing we hope the community will do is customize our software to adapt it to local environments. A rather easy but necessary part of this task would be the translation of game menus into as many languages as possible. But many other possibilities are open. For example, whatever sounds and instruments we decide to include in our games, it is clear that our choices will be influenced greatly by our Western musical culture. However it is common practice in music therapy to provide patients with instruments reminiscent of their own background. The sharing of modified, culturally specific versions of our games featuring instruments from all over the world would make this possible.

Moreover, in addition to merely customizing and localizing our games, we would like the community to express the extraordinary creativity that can be seen in so many places on the Internet. This means adding new features to the games such as compatibility with other controllers, new game modes or even completely new gameplay paradigms an data analysis algorithms. We hope that this will enable our games to evolve and stay close to the demands of their audience, but even more importantly to be adapted to new target pathologies so that music therapy can benefit more and more patients thanks to the community's efforts.

3.3 Game Design Practices

We must ensure that the applications we make are indeed games, even if they are deemed *serious*. By that we mean that they must be fun to play for their own sake, even without the motivation coming from the serious goal behind them, which should remain hidden. Otherwise, they will merely be more entertaining ways to administer treatment, which is a completely different matter. Thus, we have decided on several important features of games that we want to make sure to include in our applications and integrated them in our methodology: high usability with rich gameplay, motivating rewards and support for human interaction.

3.3.1 Easy to Use, Hard to Master

Games are supposed to be fun no matter how skilled the players are. Obviously, competitive games like chess can be rather boring if one plays against a much better or worse opponent, but contestants can usually find ways to restore a sense of fairness by agreeing on various handicaps such as different time limits or even playing blind. In essence, this is done so that the game remains meaningful with an unpredictable and potentially desirable outcome for each player.

Although they are not necessarily out of bounds, competitive games do not seem like the best choice for healthcare serious games as we do not want patients to refuse to play for fear of losing. However, the idea of ensuring potentially desirable outcomes for each player is very important: our games should be very intuitive so that people can have fun the instant they start playing. Designing with this in mind, although it was not so in the beginning of the history of video gaming, as proven for example by the inch-thick manuals of many PC games from the 1990's, is now a standard practice in the industry. The first levels are often just tutorials which restrict the available actions to a minimum so that players can have fun without feeling lost. Additionally, difficulty is usually very progressive, with only the last few levels representing a true challenge even for the average user. We intend to follow these principles by structuring our games with successive learning steps and levels of difficulty. We must also provide detailed guidelines as to how the players should be introduced to the game and taught how to play, since they will most likely do their first trial rounds under the supervision of a trained therapist.

In addition to being instantly fun, our games have to be hard and rich enough to give patients a sense of achievement and increased mastery when they successfully clear a given stage or mode. This is not an easy task as the more gameplay features we include, the more confusing things will become for beginner players. However, we think it is necessary to provide multiple paths to explore from the very beginning so that everyone is given a chance to play with his or her own style. We are after all making games with music, which is all about being creative and expressing oneself. We think that our games should reflect this mindset by including both a lot of varied content and numerous gameplay subtleties for players to discover progressively. Patients will otherwise quickly lose interest and come to see our games as just one more boring procedure, nullifying our efforts to increase their motivation and commitment to their treatment.

3.3.2 Rewarding Experience

During the NES era [91], games were often much more difficult than they are today: the last levels were frequently filled with random, instant-death traps, overwhelming swarms of enemies and ridiculously strong bosses. From most designers' point of view, this was done to artificially increase the lifespan of games without adding any content. However some people, who came to call themselves *hardcore gamers*, took pleasure and pride in training for countless hours in order to take on these seemingly impossible challenges. To this day, especially in MMORPGs like *World of Warcraft*, developers are routinely taken by surprise by the extremely short time these hardcore gamers need to discover all the new content they add and publish comprehensive walkthroughs on fan sites. However, these people, although they are very important because they are the core around which entire communities of more casual gamers revolve, make up for only a small fraction of the audience of video games. Consequently, developers have to design products that are equally appealing to all the very different types of players that exist.

One of the most important sources of motivation for gamers is the sense of achievement that comes from clearing a level, completing a quest or beating a given score. These successes are usually rewarded with new objects or capacities which add new possibilities to the gameplay and give players more freedom. However, since casual and hardcore gamers alike want to be able to beat the games they buy and see their story come to a close, developers have had to find strategies to give the later a good challenge while still letting the former enjoy the games at their own pace. Consequently, instead of making games *Nintendo-hard*, it has now become common practice to offer a main storyline or quest or game mode that the casual gamers can follow, and add secret endings, items or characters for the hardcore gamers to unlock through actions that are not necessary to complete the game. Lately, this practice has been taken to new extremes by Microsoft with its XBox Live Achievements which are handed out like medals to the most dedicated gamers for accomplishing specific, sometimes rather non-sensical actions. Although these achievements are of no use whatsoever in-game, as they do not give access to any new content, the simple fact of being congratulated for their deeds is enough for many gamers to pursue these goals, which have become the new equivalent of the random traps from the Nintendo era for artificially making games last longer.

We want our games to give patients a truly rewarding experience, with both a feeling of progressive mastery and actual new gameplay elements to discover and put to use. We therefore construct our games following the structure shared by most modern games:

- A preliminary step introducing the various basic gameplay elements, control interfaces and general feel.
- A main storyline, game mode or set of objectives which should constitute a very progressive, rather unchallenging yet rewarding experience for any kind of player.
- Multiple additional modes and extensions to accommodate hardcore gamers or simply patients with an unusual profile.

Playing through the main phase should allow players to slowly unlock most of the available gameplay elements but all game modes, including the preliminary step, should contain their share of rewards, however simple they are, since as we saw earlier with XBox Live Achievements, a little congratulation already can go a long way in motivating players.

3.3.3 Fostering Human Interaction

Facebook games like *Farmville* [92] have shown that an otherwise very classical game could become extremely popular simply by leveraging social networks to encourage interaction between players in a much more integrated way, by automatically comparing scores, publishing achievements or proposing to buy in-game gifts for your friends. One might wonder if the type of interaction induced by Farmville can rightfully be called *human*, but the fact remains that connecting players with their friends, even in such a crude way, seems to have a surprisingly high motivational impact. Clearly, we do not intend to link our games to any social network like Facebook, as privacy concerns would make it impractical. However, we do want to encourage patients to interact with their care givers, families and friends through our applications and the various community-based tools that will be built to support them.

Our primary objective is to enhance the general mood in institutions by providing patients and staff with an activity they can enjoy sharing. Indeed, severe understaffing often forces care givers to rush around, impairing the quality of their work and their morale, while leaving patients with the impression that they are not properly considered and cared for. Consequently, any kind of therapeutic activity fun enough to help the staff relax and give them occasions to interact with patients outside of the usual routine could greatly benefit everyone. Of course, we must make sure that the distinction between patients and staff remains clear even in-game, as we do not want to disturb the sometimes very fragile relationships practitioners can have with difficult patients. However, instead of trying to make games that patients could play autonomously, which usually implies sacrificing a lot of gameplay elements and configuration possibilities to keep things simple enough for diminished players, we choose to always carve a central place for the surrounding care givers, whoever they might be. This allows us to keep a substantially higher degree of complexity in our games and hopefully engage patients and caregivers together in an activity pleasurable for all.

We also want to encourage group interaction through our gameplay designs. This means making games that patients attending the same institutions can play together. Indeed, group therapy is very interesting for us as it has proven effective for the treatment of various types of behavioral issues and is usually much more efficient on the whole since one therapist can treat up to 10 patients at the same time [93]. It is worth noting here that this does not necessarily imply that our games should pit patients against one another or even give them a common goal, but simply that they must be designed to allow and encourage group interactions.

This gameplay orientation could also enable patients to play with their families and friends, at home or when they visit. Although it is much more difficult to guarantee any kind of therapeutic impact when treatment is administered by untrained non-professionals, we think that taking families and friends into account when designing our games is worth the effort. Indeed, the feeling of being left alone by their peers that chronic diseases induce in most patients, rightfully or not, is a leading cause of depression. Therefore, giving them the ability to propose a fun activity to share with those visiting should empower them greatly and have a powerful impact on their mood.

3.4 Action Research

Action Research is a methodology introduced by Kurt Lewin in 1958 [94] for doing research in the fields of sociology and anthropology. Without rejecting the classical, purely observational stance taken by most social science researchers, he thought that by inducing transformations in the groups and situations they were studying and carefully analyzing their consequences, researchers could uncover truths that would otherwise remain hidden. Unsurprisingly, the choice of the actual transformative initiatives one will take raises great methodological and ethical questions that are still debated today. However, one thing is clear: any researcher who uses this kind of methodology must ensure that the transformations he induces are beneficial for the target community and its members. We intend to follow this principle and make sure that (1) all of the patients taking part in our research and consequently testing tools and methods that were not validated still benefit as much as possible from their participation, even if the actual therapeutic impact of our games should turn out to be low, and (2) that the community as a whole benefits from our efforts through the diffusion of our tools and the knowledge they have helped gather.

3.4.1 Constant Testing and Improvement

One of the primary aspects of Lewin's methodology is iterative transformation and analysis. Broadly speaking, a social system is first analyzed following the usual observational techniques. Then, a first transformative step is implemented. The system is then *frozen* and the outcomes and underlying workings of the first transformation are analyzed. The information gathered is then fed back into the loop in order to design and implement the second step, and the process is repeated *ad lib*.

This incremental method is time-consuming and costly but has many advantages. First, it seems logical to implement the transformations in a very progressive manner, if only to be able to stop the process as soon as any detrimental effect is detected. Indeed, the outcomes of the transformative actions taken are usually very uncertain and great caution is mandatory to avoid harming the test subjects in ways that may have been completely unpredictable in the beginning. Second, this feedback loop methodology makes it possible to look at the underlying processes through which the transformations occur, while simply looking at the final outcome would yield much less information.

The incremental approach is very common in the video game industry, and is sometimes called *playtesting* [40]. It is indeed extremely hard to predict how players will react to a given gameplay element without trying it out for real, as very subtle modifications such as changing the size of a given information on screen can have a dramatic impact on the overall experience. Therefore, game designers are used to quickly putting together crude prototypes of their games to test the new concepts they want to introduce and progressively improve their designs based on the feedback they get from testers. Such a procedure seems especially adapted to making music therapy serious games: even people who work with the patients every day have a hard time seeing the world through their eyes as they often tend to think in ways very different from that of typical healthy subjects. Consequently, even though we naturally try to come up with the best first prototype possible through careful preparation with healthcare practitioners, we must be prepared to make profound modifications to our original designs as we are almost bound to be fundamentally wrong in many of the choices we make before the first trials.

Moreover, we want our games to be used in a special environment with its own, very specific and pressing constraints. As explained earlier, healthcare practitioners are almost always extremely busy and have very little time to spare to train with new tools. We must therefore make our games as easy to use as possible for them also, which means intuitive controls and configuration, compact and simple hardware and quick and easy setup. Again, it is almost impossible to obtain all this without thorough incremental testing and improvement. Staff members usually are unable to foresee the practical problems that may arise from very simple, seemingly unimportant design choices such as when to prompt for certain data or how to navigate between the different menu screens. For example, only when they are actually immersed in their demanding day-to-day workflow can they realize which features will frequently be used and need to be instantly accessible and which should be buried deeper in the menus to avoid unnecessary screen clutter.

3.4.2 Participative Design

The most important way in which we intend to have a positive impact on our test subjects is by closely implicating them in the design process. No matter what their afflictions are, chronic patients frequently feel very lonely and suffer from being considered as different or even useless. Their productive and creative potential is often overlooked and their opinions and advice are seldom truly taken into account even when they are directly impacted by the choices to be made. Of course, there are explanations for this other than the mere heartlessness of healthcare practitioners. Medical treatment is often a very complicated matter and those who design and implement healthcare systems and procedures already have more than enough to do to fulfill the medical requirements; they consequently have little time to spend on comfort features for patients. However things are changing as patients' well-being is increasingly considered, if only because on average, humans spend more and more time ill, most notably due to lifespan extension.

By closely involving our subjects in the evolution of the system they are testing, we hope to restore their self-esteem. That means showing them that we truly take their recommendations into account and actually implement some of the changes they suggest. This should have a positive impact on their well-being as they will see that even though they are sick they are considered as humans with their own needs and desires just like anyone else. Moreover, as it is games we are making, our primary objective is for our users to have fun. Therefore, putting their pleasure first when we design and modify our tools should yield the best-adapted products. Only when fun is guaranteed should we try to optimize our applications for a better therapeutic impact.

But even this therapeutic optimization is participative too, although to a lesser degree, as here we try to involve as many healthcare practitioners as possible. We expect this to both yield the best product from their point of view and grant us an important number of supporters who will help us spread our products as widely as possible.

3.4.3 Large-Scale Diffusion

In addition to the short-term impact of our research on our test subjects' well-being, we hope to have a broader, long-term impact on the healthcare community as a whole. In order to do this, we intend to design, implement, package and distribute our games in a way that facilitates their diffusion on a very large scale.

First, as stated before, our designs rely exclusively on cheap, easily available hardware borrowed from the video game industry. This way anyone in the world who wants to use our tools should be able to find the necessary equipment at a local store without having to order abroad or pay prohibitive prices.

Second, all of our games will be released under the GPL license so that they can be downloaded, used, customized and enhanced freely. This strategy is beneficial for everyone as users will be encouraged to publish their reviews, tips and modifications on a dedicated web platform.

Third, we ensure that our games are very easy to install and use so that healthcare practitioners as well as the general public can try them easily and quickly discover their potential benefits.

Finally, we hope to build a lively community of users around our games. They will frequently be consulted regarding the evolution of our software so as to make sure we implement the features that they need and will hopefully become our ambassadors among patients, caregivers and healthcare practitioners.

3.5 Data Analysis

One major difference between classical instruments and electronic ones is that the later can record much more information than the former. With regular instruments, recording movement or pressure data requires additional sensors such as cameras or accelerometers. On the contrary, electronic devices have built-in capabilities for this, since they function precisely by collecting such data and sending it to a computer for processing and sound synthesis. Consequently, one can imagine recording not only the sound produced by the patients, as music therapists already do, but also MIDI [95], movement or interaction data such as button presses. We think that in the long run this could allow for much deeper, more meaningful analysis of music therapy sessions. However very little work has been done in this field, and we consequently decide to limit ourselves for now to simple, preliminary analysis features in order to pave the way for future research, as the primary objective of our work is the design of fun, therapeutic games, not automatic diagnosis tools.

3.5.1 Automatic Logging

The first advantage of using musical computer interfaces is that everything can be stored automatically without any user intervention. With regular instruments, therapists have to go through the hassle of hooking up microphones and recording gear just to keep a trace of the sessions. This gets especially complicated if they want to record each participant separately as no reliable method exists to separate different audio sources from a single recording track [65], which means they have to install one microphone per patient. This quickly becomes unmanageable as group therapy sessions often involve 5 to 10 people. Moreover, if they want to record movement or behavioral data, they also need to set up a camera, the sight of which is bound to disturb the sessions, as it constitutes an extra presence not always welcome by patients. Finally, all this data will usually have to be replayed, cut and annotated by hand, an extremely tedious task which only really dedicated researchers are likely to have the time to accomplish.

Computerized music therapy sessions alleviate these problems all at once. Musical data can be recorded and stored automatically for each patient as well as for the entire group and replayed on any computer equipped with the same software. Movement and interaction logs provide useful additional information that was not accessible before, or solely in a qualitative form through painstaking analysis of video data. Of course regular audio and video recordings still pick up useful things that do not appear in the computerized data such as verbalizations or facial expressions, but these are very rarely analyzed thoroughly outside of a research context. Therefore it does not seem necessary to build this kind of capability into our systems as musical and interaction data should already be more than enough for most therapists.

But no matter how accurate and diverse it is, the large amount of data we can collect has to be properly organized in order to be usable. Fortunately, efficient strategies already exist for this specific task. To us, an optimal solution would be the use of personal USB keys containing all the relevant data for each patient, as is done at the InGame Lab [44], and a music therapy-oriented log analyzer such as the MT Logbook. Such a setup would allow the tracking of each patient's evolution with minimal configuration, automatically tagging and storing log files in a convenient and secure way.

3.5.2 Simple Statistical Tools

Deep statistical analysis of musical and interaction data is very complex. For example, even the most advanced algorithms for meter extraction are unsatisfying for funk or jazz songs, where the rhythmic patterns are intricate and often very syncopated, even though the overall performance of beat extraction techniques is reaching interesting levels [96]. Consequently, performing reliable semantic analysis approaching what is done by therapists remains impossible as of today. Only experienced musicians are able to detect the fuzzy rhythmic regularities that briefly appear in group improvisations performed by non-musician patients, let alone the very abstract musical forms such as the *rêverie musicale* described in [17].

Thus, we focus our work on simple statistical tools such as playing time, average volume or note density, pitch distribution etc. As previous research has shown [64], those easily computable values can already be correlated with interesting parameters such as player investment. They should for example allow for automatic preliminary detection of the salient moments of a session: it seems quite sensible that the most interesting moments of a session be those when a player is the most committed to his or her playing. Therefore, segmenting sessions according to this kind of parameter could make it much easier for therapists to analyze the collected data as they will only have to look at the portions in which at least one player seems sufficiently involved.

On a longer time scale, looking at the changes in playing time or instrument choice throughout the treatment could be an efficient way of tracking patients' evolution. For instance, playing longer or with more variety throughout the sessions should most likely be a sign of increasing mastery and interest, which should encourage caregivers to continue with the treatment. On the contrary, someone who compulsively plays the same thing over and over several sessions in a row is most likely not getting anywhere and the treatment should be modified or even stopped altogether. While in regular music therapy such assessment can only be done by a dedicated music therapist closely following the patients, simple statistical tools included in a computerized music therapy system should be able to highlight this kind of behavior and give the staff a chance to detect it even if the playing sessions are not led by the same person each week, increasing the adaptability and flexibility of the treatment.

3.5.3 Visualization

In our field and many others alike, the capabilities and prices of sensors have evolved in such a way that it has now become impressively easy to collect tremendous amounts of potentially useful data. However the statistical and classification tools necessary to extract meaningful results from these enormous databases, although they have progressed significantly, still lag behind a great deal as they have proven much harder to develop than they seemed at first. This means that, for the most part, making sense of the data collected still requires countless hours of painstaking human analysis. Of course computers enable us to perform this kind of task faster and faster as they become able to calculate increasingly complex features such as wavelet transforms on ever larger datasets, but things like unsupervised pattern extraction and matching, which is exactly what the human brain does so well, are likely to remain out of reach for quite some time.

The most common technique used to circumvent that problem is to develop powerful visualization methods, often based on rather simple tools such as the Fast Fourier Transform (FFT), Principal Component Analysis (PCA) or Cross-correlation, as is done in the MT LogBook. The idea here, instead of performing automatic clustering and classification of the data, is to find ways to present it to a human in the most suitable form for analysis and interpretation. The most efficient approach is often somewhat hybrid, with mostly automatic classification techniques that hand over controls to a human expert for some key steps that are too difficult for a computer. A good example of this is the segmentation methods used in [97]: an algorithm extracts contours automatically, a human expert crudely indicates those that are of interest, providing seeds for the segmentation algorithm which then precisely determines and follows the contours of the target objects.

We want to apply this kind of approach to music therapy session analysis. A first step would be to develop tools that enable therapists to display an entire session on screen in order to see which parts seem interesting and which do not. The piano roll visualization, now a standard in most MIDI sequencers, should constitute a good starting point. One could then imagine adding visual representations of various computed features to the piano roll such as playing accuracy with respect to a predetermined pulse, correlation with other players or even movement data such as gesture amplitude. For deeper analysis, a marker system analogous to the one described above for video recordings could be useful: when the therapist finds and marks up an interesting pattern, the computer, for example using wavelet transforms, could try to track its evolution throughout the session. This would allow for easy segmentation of the session and provide quantitative results on the ability of the patients to follow a given pattern and collaborate.

Part II

First Case Study: Wiimprovisation for Children with Behavioral Disorders

MAWii, the first music therapy system we created, lets children *wiimprovise* freely as a group under the supervision of a therapist and constitutes the first of the two case studies we conducted to improve and validate our design framework. It is the result of a close collaboration with Renaud Michel, as part of his Psychology Ph.D. thesis under Professor Edith Lecourt's supervision at the Université Descartes in Paris. They are both co-authors on the paper from which some elements of this part were adapted [98].

We chose to present our two case studies with the same structure: context, protocol, results and conclusions. Consequently, here, we first take a look at what behavioral disorders are and how they can be treated with analytical music therapy. Second, we discuss our first design and its successive evolutions through incremental testing at a day-care hospital, with the children treated by Michel. Next, we present our results and show that MAWii is indeed a viable mediation object for group music therapy, with multiple benefits that make it a useful complement or even, when necessary, replacement for traditional instruments. Last, we conclude with a review of on-going and future research, dealing mainly with industrialization and customization.

Chapter 4

Context

We designed and tested MAWii with children aged 6 to 10 treated for various illnesses, collectively referred to as behavioral disorders, at a day-care hospital in Paris. They used our system during their group analytical music therapy sessions, all organized and directed by Renaud Michel. This chapter reviews the children's wide spectrum of medical conditions, explains Lecourt's *Sonorous Communication* [17] technique and details the subtle but critical modifications contributed by Michel to adapt the usual protocol to the target population and setting.

4.1 Behavioral Disorders

The term *behavioral disorders* does not have a formal medical definition and, as such, is primarily used not in healthcare settings but in the field of education. Conditions such as Attention Deficit-Hyperactivity Disorder (ADHD), Autism Spectrum Disorders (ASD), Borderline Personality Disorder (BPD) or Pervasive Developmental Disorder Not Otherwise Specified (PDD-NOS, often shortened into PDD) are routinely designated by this umbrella word even though they have very different medical definitions according to the DSM-IV [99]. Although we are indeed dealing with healthcare here, and not education, this rather inaccurate qualification is sufficient for our purposes, as such a diagnosis is the only condition to admittance in the day-care center where we tested our system. Interested readers can refer to [100] for a detailed description of most disorders usually classified as such and their specific consequences for children, parents and teachers.

Active Group Music Therapy is a very generic method, up to the point that music therapists approach the conditions cited above in ways similar enough to work efficiently with groups of patients all exhibiting very different symptoms. Consequently our system, primarily destined to be used within this kind of music therapy groups, must be able to adapt to the very diverse needs and wishes of patients suffering from a wide variety of illnesses.

In this section, we take a closer look at these conditions to see how they might constrain and orient our design process. We begin with a quick, general review and then focus on attention and planning, two cognitive functions that are impaired in all of the children participating and that we consequently intend to target specifically.

4.1.1 Medical Description

A detailed description of the conditions we are dealing with would be very difficult to compile, as physicians themselves disagree about what exactly the terms they use should mean, and would in any case far exceed the scope of this thesis. We will simply give a very brief account of their main characteristics and point to [101] for a more accurate and strictly medical review.

Attention Deficit and Hyperactivity Disorder

ADHD is the most commonly diagnosed psychological condition in children [102]. It is mainly defined as the coexistence of inattention, with symptoms such as difficulty to plan and focus on a long task, easy distraction or forgetfulness, and hyperactivity, with extreme restlessness, inappropriate loudness or inconsiderate interruption of others. To fit the formal definition of this disorder, at least part of these symptoms must also manifest before the age of seven [99].

The most frequently administered drug treatment for ADHD is stimulant medication, for example the now infamous Ritalin [103]. Stimulants like this are very effective but are suspected to have very problematic, lasting side effects such as higher risk and severity of schizophrenia, bipolar disorders or chronic substance abuse compared to individuals diagnosed with ADHD but not treated with stimulants. Anti-psychotics are rising as an alternative treatment but also come with very dangerous side effects such as potential suicide ideation due to the blocking of the brain's reward system.

Given these worrisome facts, many families are turning to exclusively behavioral treatments, which in any case always accompany drug administration. Cognitive behavioral therapy and family therapy, for example, have been shown to have lasting effects, most likely because they help children and parents compensate and accommodate cognitive deficits [104]. Music therapy stimulates attention and self control and is overall a very good technique to implement these types of intervention [16]. Moreover, group therapy seems like a good choice as the main difficulty for these often incontrollable, sometimes violent children is their relationships with their fellow students and school's staff.

Autism Spectrum Disorders

Conditions referred to as ASD share two common characteristics: sufferers (1) possess very poor or even almost inexistent social communication and interaction skills and (2) exhibit extremely repetitive interests and behaviors which can be likened to obsessive-compulsive symptoms. Physicians distinguish three categories of ASD [105]:

- Autism, which constitutes the most prevalent form, and manifests itself before the age of three.
- Asperger Syndrome, which is similar to autism without the cognitive and linguistic developmental delays.
- Pervasive Development Disorders Not Otherwise Specified (PDD NOS), which designate similar syndromes that qualify neither as autism nor as Asperger.

More and more evidence is coming in to support the view that autism and other ASD's are not in fact single conditions but complex disorders whose main aspects have different causes that are simply likely to co-occur [105]. In any case, the physiological mechanisms of ASD's are very poorly understood, and there is therefore very little that physicians can do to treat these conditions with medication. However behavioral interventions, again mainly targeted at adapting one's environment and behavior to compensate for deficiencies and take advantage of strengths, have been shown to enhance the quality of life of autistic children and their families [106].

It is a well known fact that ASD patients are comfortable with computers, which have a very predictable behavior that appeals to them. Moreover, many autistic people are very sensitive to music, some even being very talented career musicians such as jazz prodigy Matt Savage [107]. Our approach consequently seems like a good candidate to yield a fun yet effective treatment for autistic children.

Borderline Personality Disorder

Historically, psychopathological classifications usually distinguished between two broad categories of illnesses [108]:

- Neurosis designates afflictions that involve possibly extreme distress but no delusions or hallucinations. Claustrophobia, for instance, is a form of neurosis as subjects feel uncomfortable in small spaces but will not argue that the walls are coming closer or that evil ghosts inhabit all tiny rooms.
- Psychosis, on the contrary, refers to illnesses where such delusions or hallucinations occur. Schizophrenia is the most well-known psychotic

disorder, largely because it encompasses, but is by no means limited to, the movie-friendly pathology known as multiple personality disorder [109].

This binary view has long been considered problematic as many patients tend to exhibit symptoms of both kinds, making it impossible to classify their conditions in this way: the term *borderline* was coined by Stern in 1938 [110] to designate this kind of syndromes that border on both neurosis and psychosis. Although the historical distinction is now considered obsolete, since psychiatrists have come to see mental disorders as a much more continuous spectrum of illnesses with frequent comorbidities, the term BPD has stuck. This situation might however not hold for long as this terminology, which is considered stigmatizing, is the subject of a hot debate in the psychiatric community. The new DSM-V, due in 2013, may acknowledge this and follow other classification systems such as the ICD-10 which already refers to BPD as *emotionally unstable personality disorder* [111].

4.1.2 Attention

Attention is the process whereby a person concentrates on some features of the environment to the relative exclusion of others (see Wordnet dictionary [112]). Using a vocabulary closer to that of a computer scientist, one could say that attention is the process of allocating computing resources to the various tasks at hand. However this later definition is slightly more general as the tasks at hand can be purely internal, such as investigating a given memory, and therefore need not be directly related to one's environment.

Attention is a crucial cognitive function which is very often affected by the disorders described above. Deficiencies can take a variety of forms such as the following:

- ADHD patients have trouble focusing on a given task and will be easily distracted by irrelevant stimuli.
- Autistic patients have a tendency to become obsessed with specific objects or rituals which can lead them to ignore even salient stimuli such as safety warnings.
- Many children suffering from the illnesses above have difficulties with overall control of their spontaneous response to unexpected stimuli and alternating attention[1]. They need any new activity or rule to be introduced slowly and may over-react to brutal changes in their environment out of intense distress.

Such symptoms are obviously detrimental to their social life and are arguably a sensible target for group music therapy for two main reasons.

[1] Alternative attention is the ability to switch focus from task to task.

First, as music unfolds in time and disappears instantly once played, one has to focus to stay in tempo: missing even a single beat can sometimes make it impossible to catch up for a while. Second, practicing in groups forces patients to control themselves to keep a socially acceptable behavior, even if sudden stimuli induce distress, and encourages them to distribute their attention between the members of the group in order to efficiently communicate and cooperate musically.

4.1.3 Planning

Planning consists in the formulation, evaluation and selection of a sequence of thoughts and actions to achieve a desired goal (see Wordnet dictionary [112]). It is a cognitive function just like attention, but it can be considered to be of a much higher level as being able to focus on said thoughts and actions is an obvious prerequisite to the selection of those that are appropriate.

Long-term planning, here understood as anything longer than one or two hours, is often very difficult for patients suffering from the disorders we described. For instance, the children attending the day care hospital where we performed our tests very rarely talk about the distant future; for many of them a simple reference to the following week is considered a very positive sign by the staff. Planning of this kind is consequently very much encouraged and is directly solicited in Michel's methodology, as we will see in Section 4.3.

However even very short-term planning, on the order of a second, can be challenging. The children's difficulties regarding this matter manifest in multiple ways, best characterized by their impulsive, often surprising and sometimes violent responses to unexpected stimuli. For example, a child entering a room might kick as hard as possible into a piece of furniture which he or she did not expect to be there, like a chair or an ashtray, for no apparent reason. This is often misunderstood as a propensity for violence but is in fact a result of the child's intense distress. He or she instinctively, just like any human, firstly interprets the new stimulus as a potential threat. However, unlike healthy individuals, he or she is unable to delay the automatic motor response, i.e. the kick, long enough to realize that the chair poses no threat and consequently needs not be kicked. This results in a seemingly gratuitously violent behavior that is obviously extremely problematic in a social context [13].

Again, the inherently temporal and evanescent nature of music makes it a good candidate for working on these issues. Simply put, playing music over a common pulse shared by the entire group requires this kind of short-term planning: in order to blend in one must predict the occurrence of the next beat and act ahead of time to produce the next note or sound at the right moment.

4.2 Sonorous Communication

Sonorous Communication is one of the many music therapy techniques in use as of today. It was created by Edith Lecourt [17] and bears three defining traits: it is a group therapy, it is active and it is of analytical inspiration. As such, it rests on the concept of mediation, which is also the basis for many other types of psychotherapy. However it is, as we will see, highly impractical if not downright unadapted for the children treated by Michel, who consequently had to make his own adjustments to the technique to make it usable. This chapter, which only scratches the surface and as such mainly targets readers unfamiliar with analytical psychotherapy, introduces the theoretical framework on which the actual treatment protocol Michel uses is based. It quickly summarizes the core aspects of analytical psychotherapy, then covers the central concept of mediation and finally explains Lecourt's original method in more detail.

4.2.1 Analytical Psychotherapy

The theoretical foundations of analytical psychotherapy are the same as for psychoanalysis: both approaches consider that most of the problems that adult patients experience originate in unsolved conflicts from their childhood. However, the treatment method is rather different (see [113] for a good example): while psychoanalysis is centered on free association and intends to secure patients as much as possible from any potential exterior influences, most notably by having them lie down on a couch with their eyes facing away from their therapist, analytical psychotherapy advocates a much more active way of listening to patients.

Therapy sessions are conducted face to face, usually on a weekly basis, with the therapist asking potentially numerous questions about the client's childhood, personal history, parental conflicts or any other subject. Free association is also encouraged but it is much more goal-directed than in traditional psychoanalysis, which calls only from minimal intervention from the analyst. Advocates of analytical psychotherapy try to discover harmful patterns in their patients' behavior in response to recurring situations and guide them towards new ways to think and act.

Compared to psychoanalysis, this type of approach appears more suitable for children, who are rather unlikely to be willing to associate freely for an extended period of time without any prompting from their therapist. This is an important point since, as we explain in Section 4.3, in a certain sense Michel's protocol is to Lecourt's technique what analytical psychotherapy is to psychoanalysis: Michel demonstrates the use of the instruments, asks questions and even sometimes participates in the improvisation, intervening in various ways unwanted in traditional *Sonorous Communication*.

4.2.2 Mediation

In psychotherapy, the term *mediation*, as defined by Chouvier [51], refers to any auxiliary activity supervised by the therapist in order to encourage patients to talk about personal issues that would otherwise remain untold. This concept is useful in the analysis of a large number of techniques such as play therapy, role playing or art therapy. The *mediation object*, that is to say the physical object or the activity that supports the mediation process, can be anything from a painting to a dance or a game. The only point justifying its presence is its ability to spur interesting responses, usually in the form of elaborations[2], which can then be interpreted in the usual analytical manner.

A good pedagogical example of the interest of mediation is the very common art-therapy technique of having children draw something in response to a question or a topic suggested by the therapist. For instance, given the subject's usually rather awkward nature, children will rarely be able to elaborate spontaneously on the potentially stressful fights between family members that they witness at home, let alone reflect on the influence they have on them. However, if a child always draws a brawl scene with weapons and blood and explains that the characters are members of his or her family, the situation is clearly at least worth investigating for the therapist.

Similarly, music seems like a good candidate to support elaboration for therapeutic purposes. Many patients easily invest the music they create in an emotional and metaphorical way and consequently tend to utter remarks about their own performance that reveal very precious information after interpretation by the therapist. Moreover, the music itself, especially the choice of sounds and level of interplay, can also be interpreted to yield extra information that patients unknowingly convey through their musical productions, such as who leads a group, who ignores a given person etc.

4.2.3 Lecourt's Method

Lecourt's Sonorous Communication framework [17], which is widely used in France, sees free group musical improvisation as a therapeutic mediation. Although designed independently, *Sonorous Communication* exhibits similarities with Priestley's *Analytical Music Therapy* [114], which is also based on Freudian psychodynamic principles, and *Creative Music Therapy* [16], introduced by Nordoff and Robbins, which focuses on the use of musical improvisation too. However, it also significantly differs from these two approaches. It targets group mediation, while Priestley emphasizes one-to-one therapist-client connections, and does not see music education as a therapeutic means, whereas improving patients' musical skills is one of the main goals of the Nordoff-Robbins method.

[2]Elaboration, in psychotherapy, simply refers to what a patient says when associating on a given topic.

In *Sonorous Communication*, patients are seated in a circle and presented with a set of instruments chosen by the therapist. This choice is obviously very strategic and may be approached in a variety of ways. As *Sonorous Communication* relies on free association, it seems logical to offer an instrumentarium as large and varied as possible so that patients are most likely to find an instrument they feel they can express themselves with. However too much choice may be confusing and, from a more practical standpoint, simple matters of logistics and, even more crucially, budget will often greatly limit what therapists can offer. Consequently, gathering the right instrumentarium and choosing which instruments to use in a given context requires solid experience and inevitably involves a lot of trial and error. This issue clearly extends far beyond the scope of this thesis but is nevertheless crucial for our work on two different levels:

- The overall look, feel and manipulation of our system must conform to the requirements determined by therapists.
- The choice of the sounds available to players has a lot in common with the constitution of an instrumentarium, although it avoids the issues of cost and logistics.

We come back to these two problematics and explain our solutions in Chapter 5.

In any case, each participant is invited to pick one or more instruments but may also choose to play with just his or her voice, perform body percussions or even use any kind of object that can produce sound in one way or another, such as the chair he or she is sitting on. Once they have made their choice, patients are invited to play in groups ranging from 2 to 10 persons, sometimes with other members watching and listening. The therapist steps back to watch and sometimes stop the improvisation after about ten minutes if the group cannot manage to come to a halt on its own.

The only suggestion given before the improvisation is to “communicate through sound, with eyes closed if possible”. This is very important: at no point during the session is musicality presented as a goal. Sounds are from the start understood as signs that convey some kind of meaning, and in this sense could be seen as closer to words. However it seems that the most beneficial parts of the improvisation are those when the players clearly feel that their production as a group [115] is “musical”, and often, but not necessarily, beautiful.

Indeed, *Sonorous Communication* includes three more phases that are considered to be equally important as the playing phase (see Figure 4.1): a first discussion, just after the improvisation, then a replay of the recording of the performance, and finally another discussion. Through the analysis of patients’ verbalizations and behavior during these phases, one can see that the onsets of these ”musical” moments are often the events that patients are

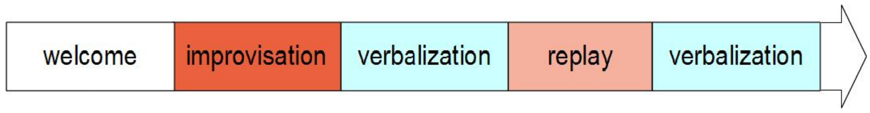

Figure 4.1: Timeline of a typical *Sonorous Communication* session.

the most willing to elaborate about, which is the definition of an efficient mediation object.

However, merely defining musicality properly seems impossible because it depends too much on the context, of which personal musical tastes are only one aspect. For example, participants in an experimented Sonorous Communication group might define musical moments as those clearly exhibiting very well coordinated intent while for the children treated by Michel the simple establishment of a common pulse already constitutes a desirable achievement. Thus, this often accepted claim about the power of "musical" moments remains very difficult to prove quantitatively, as no definition and consequently no faithful numerical measures of musicality exist.

One would necessarily have to rely on imprecise and inherently biased assessments of both musicality and degree of interest of the corresponding elaborations, obtained through the tedious systematic analysis of a very large collection of audio and video recordings. However, systems like ours may change this fact by allowing for much better automation of this kind of task. We dig further into this issue in Sections 5.3.5 and 7.3.

4.3 Michel's Protocol

Sonorous Communication could not be used as is because of some specific difficulties related to the children under treatment, mainly impulsiveness, short attention span and learning difficulties. Michel consequently introduced several significant adjustments in the usual protocol. This section presents the experimental setting and explains Michel's method, focusing on the specific changes he made to *Sonorous Communication* to fit his patients. It concludes with a brief account of his research, explaining the rationale for his specific focus on time and his subsequent interest for computer music therapy systems as a research tool.

4.3.1 Setting

Our experiments took place in an after-school intensive care center where children are admitted after being diagnosed with behavioral disorders, a very broad term that may apply to a wide variety of pathologies such as hyperactivity, borderline personality disorder, etc. as we explain in Section 4.1. Every evening, after school, the children are invited to participate, on a voluntary basis, in various activities organized by the staff, including Lego therapy, reading sessions or relaxation. They are free to roam the playground and can enter and leave an activity whenever they wish.

This type of organization motivates the children better than forced participation and clearly differentiates the care center from school, where they often struggle with classes and imposed schedules because of their deficiencies in terms of attention and planning. However, free roaming also poses a number of significant difficulties from an organizational point of view. Most importantly, it forbids planning a group progression for an activity, as the children who join late would feel lost. We explain the arrangements Michel consequently had to make with both the usual Sonorous Communication protocol and the day care center staff's practices later in this section.

The goal of the treatment is to help the children to learn how to better adapt themselves to a given social setting. This is coherent with the DSM definitions of most if not all mental illnesses which mention, in one way or another, that to justify treatment there must be clear evidence that the symptoms significantly impair a patient's functioning in terms of social relationships, education or work.

However, depending on a patient's present state, the kind of progress sought can vary greatly. For example, anxious, uncommunicative children will be encouraged to socialize and engage in group activities. But they very well might quickly switch to a state of over-excitement, in response to which focus will be put on self-control, respect of the rules and of others, and on planning before acting. In any case treatment always amounts to the reeducation of socially critical skills or at least to the compensation of their deficiencies with other, unaffected abilities through active and lightly supervised learning.

4.3.2 Michel's Adaptations

Music therapists' acute need to adapt their methods to a large spectrum of settings, cultures and personalities is a recurring subject of discussion in the field. We have covered our goals in this respect in Section 1.2, showing how crucial flexibility is for our system. Michel details how he adjusted Sonorous Communication for his purposes in eleven points in an in-depth article [116] which, as of 2010, has yet to be translated into English. We give a brief account of what we consider to be the most salient ones, summed up into five key aspects:

1. A welcoming phase is added at the beginning of the session, during which each child in turn chooses one instrument from an album handed by the therapist instead of picking it up him/herself. This is done both to avoid conflicts over choices and the degradations that may ensue, as there is only one specimen available for some of the instruments, and

to encourage patience and planning.

2. Improvisations are only meant to last for up to five minutes instead of the usual *Sonorous Communication* length of about ten. After that, the children are much more likely to experience difficulties in functioning as a group. Therefore, the therapist must be ready to stop the performance to prevent the emergence of potentially harmful processes such as violence or closing-in.

3. Michel's groups range from 2 to 4 children instead of the suggested 5 to 8 people for *Sonorous Communication*. Indeed, it remains very difficult for even the most experienced therapists to properly manage, let alone treat, more than 4 impulsive children at the same time.

4. In traditional *Sonorous Communication*, therapists favor a complete, uninterrupted replay which lets patients form general impressions on the piece as a whole as well as comments on a specific part. However children with planning difficulties cannot properly take mental notes of their comments and wait until the end to express themselves. Consequently, during the replay phase, they are allowed to pause the recording with a given hand gesture in order to express their surprise, insights and so on, even though it disturbs the replay for the other members of the group.

5. Due to the free roaming policy of the day care center, the children are allowed to come and go more or less as they wish, while *Sonorous Communication* groups are always closed. In order to nevertheless achieve a relative degree of cohesion inside groups and structure the sessions, Michel explains to the children that they have to form groups and notify him in advance, during the after-school snack organized by the staff, that they want to come play music. This both encourages planning and reassures them, as they consequently only play with partners that they choose.

Even though these adjustments are subtle and might seem unimportant, their influence on the outcome of the treatment can be dramatic. The children treated by Michel can be extremely impulsive, which makes Points 1, 2 and 3 critical as any situation of conflict can quickly escalate and become uncontrollable without force. Moreover, Michel's method is ambitious but risky, as it puts children through potentially very intense emotional states, and is sometimes seen as being on the fringe of what is considered acceptable in a healthcare setting. Even if we think that, according to our own experience, the community's fears are very far-fetched, we must acknowledge, just like Michel did, that an accident may result in the termination of the treatment, even if some children clearly benefit from their *Sonorous*

Communication sessions. We must thus act with the corresponding level of prudence.

4.3.3 Perception of Time

From a research point of view, Michel's principal interest is the perception of time and its musical alter ego, rhythm. More precisely, he focuses his work on apperception of rhythm, which is the act of noticing the presence of a regularity, usually a pulse, in a given piece of music, and acknowledging it in one's own action, for example by tapping one's foot accordingly. This is clearly closely connected (1) to attention, as a patient has to focus on the music or even specifically on a few key, salient elements to extract a regular pattern, and (2) to planning, as patients for example have to predict the occurrence of the next beat to start moving beforehand if they want to play in time.

These two cognitive processes justify Michel's emphasis on rhythm and his consequently almost exclusive use of percussion instruments. This choice might seem counter-intuitive at first, since percussions seem more likely to induce excitation or even restlessness, states which are clearly not desirable in a treatment targeting self-control, than say a violin or a flute. But although it is true that using percussions probably required Michel to be extra careful in the beginning with his impulsive patients, their affordance for rhythm exploration and play as well as their very intuitive manipulation allowed him and the children to tackle the issue of time perception much more directly and efficiently, as shown by the outstanding results he obtained.

We summarize here what he considers to be the four key points of his research, which pertain to the clinical impact of *Sonorous Communication* on his population as well as the theoretical implications of his experiments:

1. Michel's flavor of Sonorous Communication durably reduces impulsiveness as measured by the Stroop test [117]. His data shows a statistically significant difference of impulsiveness attenuation with respect to the consistency of the treatment ($p \leq 0.01$).

2. Similarly, sequential treatment, as measured by the Stambak test [118], shows a durable improvement ($p \leq 0.01$).

3. The children's temporal horizon expands: in their utterances during sessions, which were all analyzed by Michel for his research, their use of the past and future tenses augments compared to their use of the present tense. Michel also showed that this expansion correlates well with the reduction in impulsiveness.

4. Apperception of rhythm is the main support for elaboration in his population. The melodic and timbral components of the music of course

> play a role, but rhythm, and in particular the establishment of a common pulse, is by far the aspect that the children recognize the most often as being evidence of communication and interaction and is the one to spur the large majority of their comments.

In the end, Michel concludes that improvisation gives rise to elements of surprise or, more generally, to what Marcelli calls *microrhythms* [119]. With his help, by working on their perception and appropriation of time, impulsive children can learn to control their reactions to these microrhythms, as shown by the treatment's very significant impact on impulsiveness and sequential treatment.

Chapter 5

Design and Testing Protocol

After a thorough examination of our research context from multiple points of view, i.e. ours, Michel's and the children's, we come to the core of our work: the design and testing, in a real clinical setting, of a prototype conceived following the guidelines of our framework. First, in Section 5.1, we further specify the objectives we pursue and the constraints we face, as explained in Part I, in light of the experimental context laid out in Chapter 4. Section 5.2 then presents our first prototype, obtained prior to any testing through close collaboration with Michel. Finally, we explain our testing methodology, and in particular the incremental modifications we made to the system and session protocol in Section 5.3.

5.1 Objectives and Constraints

The objectives and guidelines we exposed in Part I are very general and hopefully apply to any kind of healthcare setting and any kind of pathology. In this section, we review, first, the concrete requirements and, second, the expected benefits they imply in the particular context of the treatment of children suffering from behavioral disorders via *Sonorous Communication* in a day care hospital.

5.1.1 Specific Requirements

The overall goal of our research is to explore the potential benefits and caveats of introducing computer and video game technology in music therapy. We think this is a worthwhile effort, especially regarding the specific age group we are targeting here: children today are so familiar with these technologies that they often do not even consider them as advanced anymore. Psychotherapy has to follow through or it will be at risk of losing contact with its younger patients, who will have a hard time understanding their therapists' reluctance to use technologies that are like a second nature to them.

Given the widespread skepticism of music therapists towards computer technologies [39], a necessary first step is to show the feasibility of our approach. This means demonstrating that a computer-based system can be used in an actual clinical setting and perform the same role of mediation object as traditional instruments without any significant modification of the usual protocol. In particular, this means responding to two major objections often made by music therapists.

Firstly, non tech-savvy health care professionals must be able to use their computer systems in clinical settings with patients who require constant attention and who may easily give up if something does not work properly right away. Hence the requirement for our system to be easy to use, but most importantly very robust, so as not to lose our patients' attention because of delays due to technical failures. As we explained in Part I, this is almost always the case for systems targeting healthcare environments, but this constraint remains far more pressing with impulsive, easily distracted children than for example with Alzheimer patients, who usually are rather patient and unlikely to throw a tantrum out of boredom.

Moreover, engineers and technicians are often forbidden to enter institutions such as our day care center. Though the need for their presence in the clinical universe is increasingly acknowledged, ethical and safety concerns frequently prevent them from being there to fix things on the spot when necessary, making robustness and quick recovery from failure even more critical. This is especially true for analytical psychotherapy techniques such as Michel's, since even if they were indeed allowed inside the institution, engineers' intervention during in the middle of a session would probably be too much of a disturbance anyway. Indeed, while many other, more behavior-oriented methods are more or less indifferent to this kind of interference, Michel reported that the mere presence of another psychologist from the institution, whom the children knew very well, already was enough to render the sessions unmanageable. It is thus likely that in case of failure, even the most discreet appearance by a technician would not be tolerable, leaving Michel with no choice but to continue the session using normal instruments only.

The second, more profound issue is the validity of artificial interfaces as mediation objects, despite their lack of corporality. Indeed, compared to traditional instruments, affordable devices such as the Wiimote have a plastic feel and produce their sound through distant speakers instead of vibrating themselves. Moreover, traditional instruments come in a very large variety of sizes, shapes and textures which significantly contribute to their identity, whereas all Wiimotes look exactly the same. Consequently, music therapists often remain skeptical about the capability of such systems to trigger a true emotional and creative response from patients.

Therefore, another goal of our experiments is to show that properly designed artificial interfaces can retain enough emotional charge and musical expressiveness to support creativity and symbolization to an acceptable degree. If this turns out not to be the case, it will be impossible to leverage the numerous extra possibilities they offer compared to traditional instruments, however useful these might seem.

5.1.2 Potential Benefits

To make a "business case" for the introduction of *Wiimprovisation*[1] in a therapeutic setting, an objective assessment of its many possible positive impacts needs to be made.

First, in addition to the general benefits to be gained from computer technology, such as greatly reduced burden and cost, we aim at properly leveraging the great motivational power of video games to improve patients' commitment to their treatment. This is not as straightforward as it sounds since, as explained by G. Denis in his study of the game Pads'n'Swing, which we reviewed in Section 2.2, not all motivating aspects of video games are compatible with creativity, which is very important in music therapy and absolutely central in *Sonorous Communication*. However, we think that the aura of fun that devices like the Wiimote carry can greatly appeal to children and motivate them to better focus during their work with their therapist.

Second, with a proper interface, instruments combining virtually any conceivable gesture and sound can be created. Therefore, video game technology gives us the ability to personalize each child's instrument according to his or her wishes. This means that therapists can adapt the instruments to patients' skills and, if necessary, their disabilities. Thus, a child who does not know how to or even physically cannot play guitar may still be given the possibility to use the Hendrix-like sound he or she loves. Furthermore, the children treated by Michel come from multiple cultural backgrounds and may have a special feeling towards a rarer, folkloric instrument such as the derbuka or the kora. Our system enables Michel to have the children play with what could potentially be their *ferryman instruments* (see Section 1.2.3 and [49]), while buying their real-life counterparts would be far too costly.

A third, less obvious but in our opinion maybe even greater benefit is the possibility for the therapist to go beyond simple adaptation and progressively build a custom instrument with each child. We think this would be an excellent way to maintain interest and improve self-esteem by accompanying progress and rewarding mastery with new capabilities and personal sounds, very much like what is done in the video games the children are used to playing. Furthermore, from a therapist's perspective, such a process could be used to assess a child's evolution by looking at the choices he or she makes for the customization of his or her sonorous avatar. Are they made on the

[1]We coined the term Wiimprovisation to designate the whole therapeutic protocol based around improvisation with the Wiimotes.

spot at random or do they reflect a general plan? Are they confined to a single sonorous area, such as percussions or melodic instruments only, or do they highlight a willingness to explore and experiment? Answers to questions like these, and many others, could reveal a lot about a child's inner world and help therapists build a stronger, more efficient therapeutic relationship.

Finally, we can foresee two specific enhancements regarding data collection. First, MIDI data is far easier to analyze automatically than raw audio, as it contains a lot of semantic data such as note pitches and onsets. Although reasonably efficient algorithms exist for extracting this information from multitrack audio [65], using MIDI saves a lot of preprocessing and easily captures even the most intricate or cluttered patterns, such as piano clusters, which are beyond the reach of even the best pitch recognition software. Second, movement data is very hard to obtain with traditional instruments, as one has to use complex motion capture systems which, even though their cost has plummeted, remain out of reach of most music therapy researchers. On the contrary, the Wiimotes provide a very straightforward way of obtaining this kind of data, which may provide interesting clues that cannot be detected in the music itself.

5.2 First Design

From a technical point of view, MAWii is very similar to the setup used by live music performers, especially that of the so-called Wii-Jays. We decided to use a computer hooked to a stereo amplification system through an audio interface and a maximum of six Wiimotes, connected to the computer via Bluetooth. The program Glovepie [84] processes the information sent by the Wiimotes, which mainly consists in accelerometer measurements and button presses, and maps it to MIDI messages to recreate a behavior inspired from percussion instruments. These messages are then fed to a sequencer, in our case Reaper by Cockos [120], to record everything and drive the synthesizers to produce the sound.

In this section we review these design choices in detail. We begin with a technical overview, then focus on two distinct components of the control scheme, triggering and navigation, and finish with a brief account of our preliminary protocol.

5.2.1 Technical Overview

The hardware and software we used for our first prototype was not ideal in any way and was indeed largely modified in subsequent versions. However we think it is still interesting to detail as it shows what constitutes a good basis for quickly putting together a crude prototype of a music therapy system.

GlovePie

Carl Kenner's GlovePIE [84] is a scripting language that interfaces numerous types of devices with a Windows PC. We use it to handle and process the data sent by the Wiimotes. It offers many useful, high level functions such as a built-in algorithm to filter out gravity in accelerometer data. With this software, complex MIDI message triggering systems can then be implemented in a rather simple way. Several classical instruments besides drums have been mimicked this way, with varying success: guitar, turntables, slide flute and probably many others (see the forums on the GlovePIE website for more information).

Reaper

Reaper is a very powerful, all-purpose sequencer that comes for a very fair price compared to other professional software suites [120]. It allows us to process all the data sent by the Wiimotes via Glovepie on different MIDI ports and then forward it to the synthesizer. Reaper makes it possible to record, view and manipulate the MIDI data in a simple way thanks to its intuitive multitrack routing and piano-roll editor.

XV-2020

The XV-2020 is a wave-table synthesizer manufactured by Roland. Its wide range of sounds and easy configuration and setup makes it a viable option for a first prototype, even though carrying an extra piece of equipment is not ideal. Indeed, we favored cheap, robust hardware over expensive software synthesizers, even though we intended to replace the XV-2020 with free software like FluidSynth [121] at some point to make the system as compact and low-cost as possible.

5.2.2 Triggering Mechanism

A video of WiiDrums [122] helped us realize the potential of Wiimotes as percussion-like instruments: motion sensing makes it possible to design a very straightforward interface inspired from the most intuitive instrument, the drum. We build upon Bob Somers' work but modified it quite a bit to fit our needs. First, instead of using the Wiimote-Nunchuk combination, we use two Wiimotes per child to keep a simple, symmetric design. More importantly, we implemented a much more complex triggering algorithm. Indeed, WiiDrums does not make any difference between the strokes; this means that whatever force is put in, it would either do nothing or produce sounds at maximum volume, greatly impairing expressiveness.

However, it is mathematically impossible to infer the velocity of the Wiimotes with just the three-way accelerometer they carry, as one needs 6 independent equations to compute the movement of a solid body in 3D space [123]. Therefore we chose to implement an acceleration-based triggering system instead. Our algorithm looks at the acceleration of the Wiimote with respect to its own Y axis[2], to detect strokes and compute note velocity. The formula we use is very simple and depends only on the maximal value of the acceleration during the stroke but nevertheless works rather well given the relatively poor quality of the data sent by the accelerometers. Moreover, thanks to Glovepie's gravity filtering, it is possible to work directly in the referential of the Wiimote, which gives the user some extra freedom of movement. Indeed, with gravity filtered out one can use the Wiimote horizontally, vertically or even face down, creating a relation to space radically different from that of a classical drum.

Interestingly, in the end, our interface does not work like a drum kit at all, since volume is determined by maximal acceleration and not by velocity on impact. Nevertheless, we think it retains enough of a drum-like feel to remain intuitive. With a little practice it can even be controlled with surprising precision, although informal testing proved that mastery of traditional percussion technique is of little help.

5.2.3 Sound Choice and Navigation

Obviously, one of the great advantages of the Wiimote is that it can be used to control any synthesizable sound. Therefore, instead of having just one instrument each, we wanted to give the children the possibility to have as many instruments as they would like. For the first test however, we restricted ourselves to using up to three instruments with four sounds each. Limiting the number of instruments instead of making them all available, we thought, would prevent the children from getting confused by too many alternatives[3] which would in the end render informed choice impossible. However, we retained a design using the Plus and Minus buttons to cycle through the different instruments, as opposed, for example, to Buttons One and Two respectively simply switching to Instruments 1 and 2. This way, as many instruments as needed could be added later on without changing the controls (see Figure 5.1).

Like in WiiDrums, the sound produced depends on which buttons are pressed at the instant the MIDI message is triggered by the stroke. The choice of four sounds was constrained by the design of the Wiimote since for a child's hands, only Buttons A, B and the directional pad seemed easily reachable (see Figure 5.1). Making different directions of the D-Pad code for different sounds was too confusing, so we ended up with four distinguishable messages, no button, A, B and D, that we assigned to four different sounds. To keep a coherent design, we chose to arrange the sounds by pitch, which

[2] As labeled by Glovepie.

[3] For instance, the General MIDI standard includes 128 usable timbres.

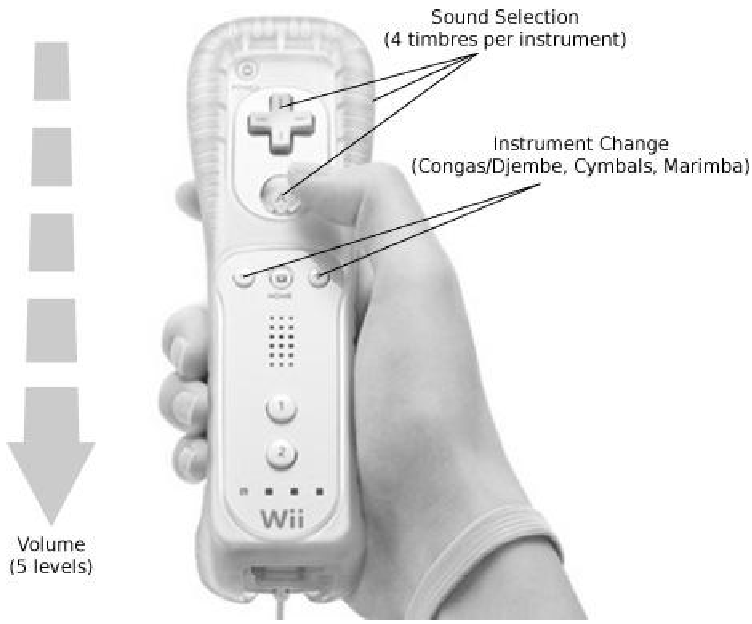

Figure 5.1: Wiimote controls for the very first version of MAWii.

gives, in order of increasing priority[4]: no button for the lowest pitch, lowest priority sound, B, A and finally D-pad for the highest pitch, highest priority sound.

We also wanted the instruments to have very different personalities but still fit well together. This meant that the sounds we chose had to be easily distinguishable but also that those that were too aggressive or too loud were not usable, to ensure that no instrument would cover the others. And, again so as to not confuse the children, we decided to use sounds to which they had access during previous sessions with real instruments. After careful review of the sound bank of the XV-2020, of which many elements were deemed unusable by Michel because of their synthetic feel, we ended up with two inharmonic percussion instruments, a conga-djembe mix and a set of cymbals, and one melodic percussion instrument, the marimba.

5.2.4 Preliminary Protocol

For this first technical validation experiment, we chose to give the children very little explanation about the system, in keeping with the traditional practice of *Sonorous Communication*, which aims at influencing patients as little as possible in their process of discovery and improvisation. Michel sim-

[4]Here, priority refers to the choice of what is going to be played in case of conflict. If multiple buttons are pressed at the same time, only the sound with the highest priority is triggered.

ply had them try the Wiimotes out a little bit during the welcoming phase, explaining only once which button did what. It was already obvious that the children would not retain much information from this first explanation, but we were much more interested in watching them experiment to understand the behavior of an unknown object than in seeing how well they could learn to do what their therapist told them to. This is after all the way most if not all children try out something new, jumping in directly and very rarely taking any time to listen to the explanations of the care givers.

However, we chose to divert a little from the standard protocol regarding the way they were presented with our system. They were of course told that they were participating in a research experiment, as is mandatory for any clinical trial. But, following Action Research principles, the therapist implicated them further by stating that the goal was to design an instrument for them. They were encouraged to share their opinion about the system, give it a name, ask for modifications, etc. We thought that putting them in the center of the design process would not only have a positive impact on their self-esteem but also would give us hints about how to implement personalization. Which features would make them think of an instrument as their own? Would the prospect of *Wiimprovising* again in a few months with an instrument they partly helped improve and could rightfully consider as theirs encourage them to project into the future in spite of their planning difficulties?

5.3 Incremental Testing

Following the principles of Action Research, we put our first prototype to the test in real clinical conditions very early in the design process. We then collected feedback from the children on a weekly basis and implemented subsequent modifications after thorough discussion with their therapist. In this section, we detail and motivate these modifications, grouped into four types: technical, interface, sonorous and finally protocol changes.

5.3.1 Technical Modifications

For the second phase of the experiment, which started about four months after the first, preliminary test, we switched from hardware to software, sample-based synthesizers. We used two VST plugins by Native Instruments [124]: Battery for percussion sounds and Kontakt for the rest. Although these programs are more expensive than the XV-2020, which is not free either anyway, they are much more powerful and flexible. Firstly, one does not need to carry an extra MIDI synthesizer anymore. Indeed, with the proper ASIO drivers, any modern laptop is powerful enough to take care of everything on a software level [125]. Secondly, Battery and Kontakt come with a very large sample database that provides access to many more sounds than the XV-2020. Finally, their powerful interface makes it a lot easier to configure and tune the different samples, add effects, compress the signals and so on.

At first, we wanted to switch directly to free synthesizers and samples to fulfill our objective of creating a low-cost, fully and freely customizable system. However quick tests revealed that free alternatives such as FluidSynth [121], although powerful, were not nearly as flexible as Battery and Kontakt. A few technical issues, especially in terms of integration with the rest of our software, and their somewhat difficult to use customization features were not compatible with our weekly schedule for implementing modifications. We consequently decided to use commercial software for prototyping before making a fully free version once a stable design had been reached.

To take advantage of this large, very flexible database and give the children a broader choice of instruments, we implemented a simple GUI for the therapist. It makes it possible to associate between one and three instruments to each pair of Wiimotes by clicking on their corresponding images. The automatic session manager then starts all the necessary software with the proper configuration. These usability improvements were fundamental for Michel, who already has a hard time handling the children without having to tinker with a complex computer setup. He repeatedly insisted on the fact that any change in the interface that could spare him even a few seconds was worth implementing, since a few moments of inattention may compromise an entire therapy session. However the system remains perfectly usable without a custom GUI, then giving access to many more sounds and options through the direct manipulation of the sequencer and synthesizer settings.

5.3.2 Interface Changes

Although the children understood the triggering mechanism right away during the first test, they had great trouble with sound navigation. They did not seem to understand the difference between sound switching and instrument switching: for them, pressing a button changed something, and that was all. In particular, they failed to realize that some buttons only affected the current stroke while others had a lasting effect, as they switched instruments.

To make it simpler, we decided to assign a button to each instrument available instead of using Plus and Minus to cycle through an arbitrarily large number of them: Minus, Home and Plus where chosen to respectively switch to the first, second and third instrument (see Figure 5.2). This meant that players would never be given access to more than three instruments at once, but this was not problematic as it became clear after the first test that the design we had agreed upon with Michel, although it was already satisfactory in many respects, was still far too complex. Three instruments would be more than enough for even the most skilled children, at least for their first year or so of practice.

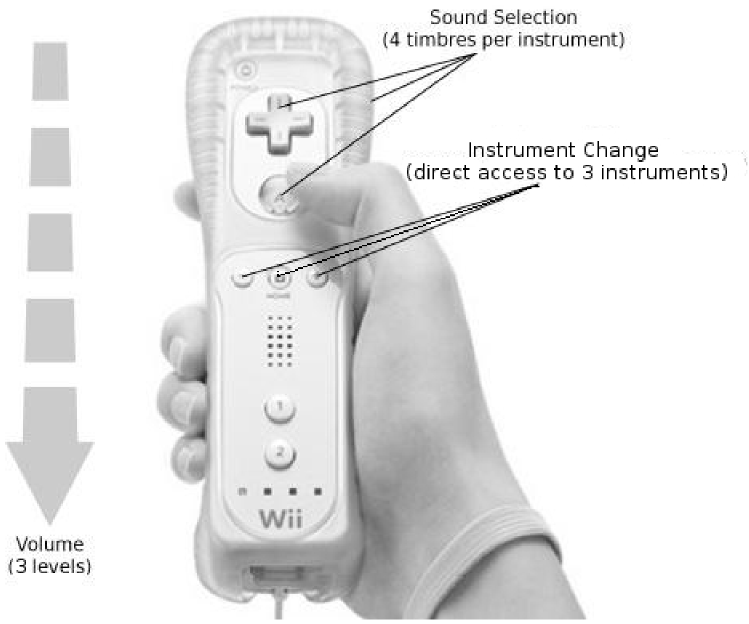

Figure 5.2: Wiimote controls for the second version of MAWii.

This was also true for volume, although to a lesser extent. High sensitivity and large dynamic range were favored at first to enhance expressiveness and encourage the children to focus on fine motor control. However it clearly appeared during the first test that they would not make use of such precision in terms of velocity, so that we could trade some expressiveness for easier control. Consequently, whereas the first version was very sensitive and had five volume levels available, Version 2 only offers three levels and requires quite a bit more effort to trigger the sounds.

5.3.3 Sonorous Exploration

One of the children's main concerns when they tried the first version was the fact that too few instruments were available. They instantly understood that virtually any sound could be built into the system and asked for a flute, a guitar, a piano and a derbuka, sometimes even spontaneously before the therapist asked for their opinions or advice. It was clear that a large sound palette was very important and that the limited instrument bank of the XV-2020 was not going to satisfy them. Although several other factors played their role in our choice, this was our main motivation for switching to commercial, professional-grade software synthesizers.

Indeed, with Battery and Kontakt it became very easy to make many more instruments available. Since it is very hard to predict which instrument will appeal to which child, we decided to cover as broad a spectrum as

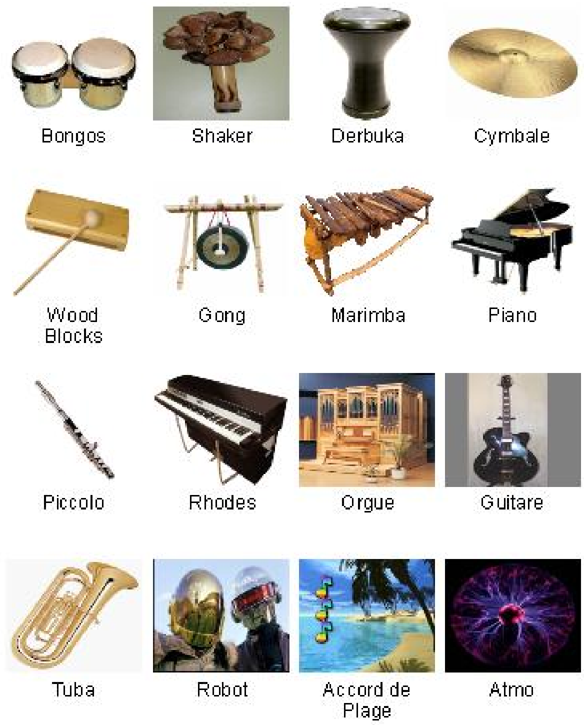

Figure 5.3: Instrument palette for MAWii.

possible and see what would happen. Thus, we blended classical percussion and melodic instruments (cymbals, congas, flute, guitar...) with traditional folklore (woodblocks, gong...) and synthetic sounds ("robot pulse", "atmospheric ambient", ...): we decided upon 6 percussive instruments and 10 melodic instruments, with 3 of the later using clearly synthetic sounds, for a total of 16 available (see Figure 5.3).

While the XV-2020 version only gave access to percussive instruments, the new version using software synthesizers also includes instruments such as the guitar or the flute which, in real life, are not manipulated at all like a drum. However, with our system, no matter the instrument chosen, everything works like a percussion. Therefore, we were able to give the children access to sounds they could not normally use without confusing them with a new control scheme, which proved to have a very positive impact (see Chapter 6).

5.3.4 Protocol Enhancement

In order to provide some clues about the lasting value of our system, we changed some aspects of the session organization during the second testing phase. Upon arrival, the children were shown a slide show presenting the instruments and the sounds they make (see [126]). Then, they were invited to choose only a single instrument for the session, which prevented them from being overwhelmed by the excitement induced by too large a choice. We did not give up on having them play with multiple instruments but decided, following video game design best practices, to make these extra instruments available one at a time, as a reward for their progress throughout the year.

Furthermore, the children chose their instrument from a booklet handed by their therapist which contained images of all those available, with the real ones on one side and the MIDI ones on the other (see Figure 5.3). This is crucial as, unlike in the first experiment, our system was this time given the exact same status as the usual instruments. We would thus see whether the children continued to use the Wiimote system or reverted to the standard percussions, determining whether the success of the first test was simply due to their attraction towards novelty or actually revealed a surprisingly good fit between MAWii and its target users.

Finally, an extra phase was added during which, once they had chosen their instruments, the children were invited to re-explain how the system worked. If needed, the therapist then guided them through a small tutorial introducing the different sounds, again diverging from the traditional methods of Sonorous Communication. This was done to help the children understand the way MAWii worked, as contrarily to regular instruments, the manipulation of which is fairly obvious, the use of our system required them to learn the logical but nevertheless arbitrary mapping from commands to sounds. Additionally, the introduction of this phase was preparing future evolutions, as it was the moment that, in the future, we intended to invest to describe new capabilities such as using several instruments to the children who started to show boredom due to increasing mastery.

5.3.5 Data Collection and Processing

All of the improvisations were recorded as both audio and MIDI files. As mentioned in Section 3.1, Wiimotes suffer from quite a lot of jitter and mathematically cannot perform one-to-one motion sensing. Therefore, we were unable to extract any meaningful information from the movement logs beyond what was already recorded in the MIDI files, and decided to discard this data. However our experiments took place before the release of the Wiimote Plus accessory, which contains a gyroscope. Had we been able to use it, we probably could have made much more sense of the raw movement data sent by the Wiimotes.

The audio files were carefully reviewed by Michel for the purpose of his own research about time perception; all the utterances quoted in this part of our work come from his notes, since we were not allowed to attend the sessions in person. The analysis of improvisation recordings is one of the core tasks of traditional music therapy and is very well covered in [127].

Our system does not bring anything new from this point of view since, as we explained earlier, automatic analysis of polyphonic audio files remains extremely difficult for computers, which means that everything still has to be done by hand.

However it is worth mentioning that using a full-blown DAW (Digital Audio Workstation) like Reaper instead of a mere MIDI sequencer makes it extremely easy to synchronize audio and MIDI tracks, as they are handled in very similar ways. Therefore any clues gathered from the MIDI files directly benefit the audio analysis. For example, the piano roll view obtained from MIDI data makes it much easier to jump from point to point in the audio file to listen to a specific player because it clearly shows who was playing what instrument and when.

Apart from using it for visualization, we extracted a few simple statistics from the MIDI data. As each Wiimote uses a separate MIDI port and each instrument uses a separate channel, it was very simple to compute the following figures:

- Number of strokes using a given button.
- Time spent using a given instrument.
- Number of instrument switches.
- Number of times a given instrument was chosen.

We use these simple, automatically computed statistics to back some of our claims in the next chapter which, if it feels natural or even absolutely unavoidable in the field of computer science, remains rather uncommon in analytical music therapy research.

Chapter 6

Results

To be an effective tool for mediation, our system must help patients to express feelings, emotions and observations about their inner self. We report below on issues such as ease-of-use or motivational and psychodynamic processes that suggest that we indeed reached that goal.

6.1 Usability

Patients' responses to a given instrument or sound can be extremely diverse and unpredictable, sometimes even triggering spectacularly and counter-intuitively positive effects. Thus, in spite of the skepticism we met when we exposed our ideas to the music therapy community, our first test had left us with little doubt that our system would appeal to at least a few patients who would find in MAWii something dear that they missed in the traditional instruments available to them. The real issue consequently was not one of potential but one of practicality: could MAWii truly be used in a real clinical setting without compromising existing treatment protocols? Our tests showed that it indeed can, thanks to its robustness, its seamless integration within Michel's protocol and its instinctive manipulation.

6.1.1 Robustness

MAWii ran and recorded successfully during 25 out of the 26 sessions in which it was used. We in part owe this to Michel's relative computer proficiency, as he did have to restart the software at the beginning of two sessions, due to synchronization problems in the software synthesizers. Nevertheless, we think that these results show that the system is already simple and reliable enough to be used in a clinical setting, despite its being an early prototype. Several concerns however arise for future, large-scale diffusion:

- Bluetooth protocols, commonly referred to as Bluetooth stacks, lack standardization and are often quite buggy. Although we have shown that this does not pose a major threat, it might constitute a problematic barrier to entry as it could make the very first setting up of MAWii too complicated for untrained professionals.

- The power button in the upper right corner of the Wiimotes seems to turn them off when it is pressed. One must then restart MAWii from scratch to get them to work again. As we have been unable to prevent this behavior at a software level, therapists may have to physically remove or hide this button, like we did.

- As with any real-time application, synchronization problems may surface, for example causing unwanted clicks in the audio stream or failing to keep the delay between the stroke and the actual sound unnoticeable. Again, this may be an issue for first-time users. Almost all audio hardware, even the chips included in low-grade laptops, has now reached an acceptable level of reliability, but not all therapists will be familiar with ASIO[1] and its sometimes tricky configuration.

These issues are not major but are still worth tackling, as we have seen countless interesting projects fail to gain widespread acceptance for seemingly even less important problems. This means that a production version of MAWii will have to include a powerful installer, capable of detecting and solving as many hardware conflicts as possible, and very detailed installation notes with a focus on ASIO configuration. In addition, we hope that the community of users that we will try to federate around our system will be of help here, especially through the animation and moderation of help forums.

6.1.2 Easy Integration

Staff members in institutions such as ours usually have to work on a very tight schedule if they want to take proper care of all their patients. That is particularly true of Michel and of psychologists in general, as they very often have to share their time between several institutions that may be far apart from each other. Consequently, any new tool they try out must take at most a few minutes to set up because they do not have any more time to spare, especially when working with impulsive patients who get frustrated very fast when one has them wait. For that reason, we worked closely with Michel not only to design the best music therapy instrument for the children, but also to simplify and automate as many setup and configuration tasks as possible.

We managed to obtain a system that could be ready to use in less than five minutes, which was sufficient for Michel. However we found no robust

[1] Audio Stream Input and Output, the most widely-used audio management standard among music professionals [125].

way of connecting the Wiimotes automatically: the unsatisfyingly time consuming manual linking procedure we agreed upon for the first test remains mandatory despite our efforts to automate it. That is one of the reasons for our thinking that Wiimotes are not at all the ideal tool for music therapy. They have many advantages over the other devices available, but lack complete integration in the Windows or Mac environments. Once motion sensing controllers become a standard for computers, we hope to upgrade our system so that it becomes as easy to setup as the XBox 360 controllers already are on Windows [128].

Apart from this issue, we can say that MAWii integrates very well into Michel's protocol and most likely will fit into the large majority of active music therapy methods. Apart from the very first sessions, for which most if not all of the children chose to use the Wiimotes because of their strong attraction towards novelty, instrument choices were rather well balanced between regular and electronic ones. In the end, MAWii was actually used by at least one child during 44% (26 out of 58) of the sessions during which they were available. More precisely, 42% (52 out of 124) of the instruments[2] chosen were Wiimote-based, with an overall domination of the guitar with 25% (13 out of 52) of the choices, the piccolo coming in second far behind with 12% (6 out of 52) of the choices.

The many successful improvisations that blended real and virtual instruments together show that our system is a viable and meaningful addition to the usual instrumentarium. Furthermore, although we do not at all aim at replacing traditional instruments, we can safely say that therapists willing to take advantage of the compacity of our system to deliver music therapy treatment in places where they cannot bring their other instruments should be able to conduct successful sessions using MAWii exclusively.

6.1.3 Intuitive Playing

Even though good usability for therapists is crucial for the diffusion of MAWii, the heart of the matter is still playability for the children. In this regard, we showed that our system offers a gameplay intuitive enough for all of Michel's patients to have fun instantly. More precisely, all of them quickly understood and mastered MAWii's triggering mechanism: several groups rapidly managed to achieve meaningful rhythmic and timbral interaction and collaboration, despite the crucial difference in manipulation compared to the regular percussions they were used to, which are based not on acceleration but on velocity and have a tangible surface to hit. Moreover, during our demonstrations, music therapists were routinely amazed by the number and quality of the sounds available, but for most children the new

[2] 124 is the total number of instrument choices that were made. For example, a session with two children allowed one instrument each accounts for two choices, while a session with three children allowed two instruments each accounts for six.

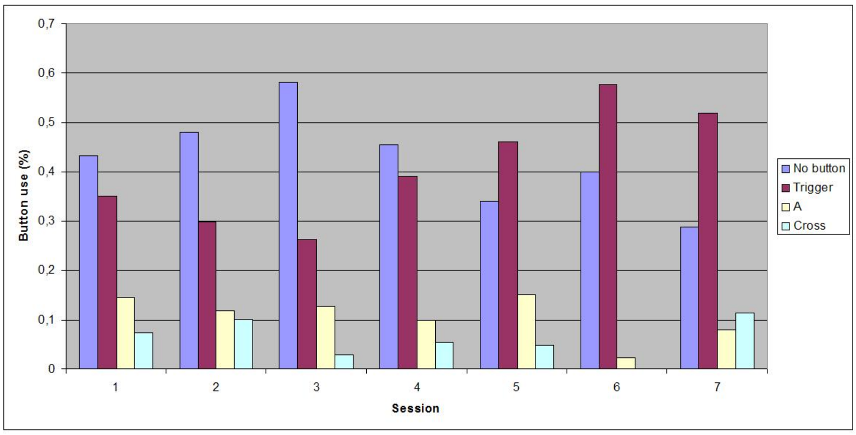

Figure 6.1: Mean button use as a function of the number of sessions attended.

capabilities our system offered seemed absolutely natural. They asked for additional instruments such as the derbuka on their very first trial and very well understood that virtually any sound they had heard before could be manipulated with the Wiimotes.

As Figure 6.1 shows, Sounds 1 and 2, respectively associated with empty, i.e. button-less, and Z strokes largely dominated, with Sounds 3 and 4 (associated with button A and the D-Pad) making up for at most 15% of the notes played. This demonstrates that:

1. The children very well understood the functioning of the system and were able to use all 4 sounds from the very beginning.

2. Four sounds is more than enough, as communication and interaction can be established with just two, since many successful improvisation relied almost exclusively on Sounds 1 and 2. Sounds 3 and 4 mostly served to sporadically break from the repetitive use of the other two in order to add accents or surprises.

Of course these results are in part due to the fact that Buttons A and D are harder to reach than Button Z. However Button A remains easy to use even with a child's small hand and indeed served as a frequent means to add accents or elements of surprise, a role we had intended for the D-Pad at first. One could argue that Sound 4 consequently is superfluous, which is true in a way, but we nevertheless plan to keep it in the next prototype as we do not see any obvious advantage to its removal.

Although the children's response was very positive overall, we did identify two important flaws in our system. First, it is technically very difficult, if at all possible, to simulate the behavior of a normal percussion with Wiimotes. The acceleration-based scheme we devised instead was far more difficult to control and playing complicated patterns required a good deal of training.

The children consequently were never able to play very precisely and even though it did not seem to bother them, as they rarely do so even with regular percussions anyway, the introduction of MAWii did make improvisations slightly more chaotic.

Moreover, only the most skilled and persistent children were able to reach a level of mastery sufficient to make use of multiple instruments at once. When they first tried this new feature they spent roughly the same time on each instrument but, on average, changed from one to the other 13 times during the 5 minutes an improvisation lasts. This amounts to a switch every 23 seconds or so, which shows that they still did not understand the radical difference between instrument change and timbre change in spite of the interface modifications we implemented after the first test. Thus, they pressed the instrument switch buttons roughly as often as the two least used timbre buttons, A and the D-Pad. There are several possible explanations for this but we will not go through them here as we did not have the time to collect enough data to test our hypotheses. However we will discuss this issue and possible solutions in Section 7.2.

6.2 Motivation

The second experiment confirmed the marked motivational power of our system, which the first experiment had already suggested [129], showing that the children's interest was not merely a matter of novelty. We can see two major forces at play here, which we discuss in this section: the cultural resonance of video games and musicianship and the increase in self-esteem due to the children's involvement in the design process. We then conclude with a review of some positive behavioral changes which could be attributed to this increase in motivation, although it is of course impossible to prove an actual causal relationship as the introduction of MAWii is far from being the only factor at play.

6.2.1 Cultural Levers

The children always referred to the system as "the Wii" although there was no actual console anywhere. There was not even a screen, for that matter, but we still undoubtedly, and on purpose, took advantage of the aura of fun the Wiimotes retained. The children said things such as "It's just like on TV" or "I played the Wii, I played the Wii!" (running around telling everyone in the institution after the first session), showing that to them Wiimprovisation was very much like playing video games. Furthermore, just like Guitar Hero and the likes, our system seems to combine the aura of video games with the very positive social image of musicianship. The children for example said things like “Now I'm a real musician !” or “I'm XXX in Star Academy[3]” which proves that, even though it does not offer the same kind of custom interface as *Guitar Hero* or *Rock Band*, MAWii still provides the illusion of virtuosity that played a major role in the success of these games.

More importantly, we think the children's choices of virtual instruments best reflect this cultural aspect. Indeed, we were very surprised to see that they showed almost no interest for the percussion instruments proposed. Instead, they almost always chose to use melodic instruments, even though they had percussion-like controls. Obviously, this is in part due to the fact that they had traditional percussion instruments at their disposal, but MAWii did offer quite a few that were not part of Michel's instrumentarium and did not have any success either. Furthermore, they were much more attracted to classical instruments such as the guitar or the flute than to the synthetic instruments we thought they would love. Our view is that, in contrast with older generations, the children did not associate the Wiimotes or synthesis technology with robotic or futuristic sounds. Such devices are simply part of their natural world and are seen not as high-end technological gadgets associated with some kind of electronic revolution but simply as opportunities to simulate otherwise unavailable instruments.

This provides interesting clues about the children's relationship to technology and shows that MAWii added two promising enhancements to Michel's protocol:

1. We remedied the lack of a melodic component to the improvisations, which seems to be central in the children's vision of music, at least in our population.

2. We gave the children access to the social value of musicianship, which seems to be much better incarnated by the instruments usually seen in the media (guitar, piano...) than by regular percussion instruments.

These two contributions would have been very difficult to implement without the use of a computer system and, from our point of view, already justify our work even if the actual therapeutic assessment has not yet been conducted.

6.2.2 Participative Design

Among other things, during the first test, the children asked for a guitar and a flute and for colors to mark the different pairs of Wiimotes so that they could recognize their own. They were obviously delighted to see that, for the second experiment, we had modified the system according to their wishes. Even though they never met the other designers besides Michel, who were not allowed in the institution, they nevertheless were very interested in the “someone somewhere” who created and modified these instruments especially

[3] A French talent show.

for them. They asked lots of questions and were eager to suggest names for the system as well as new features to add to it, showing that being at the center of such a process greatly raises their confidence and self-esteem. We see this as a very strong hint that reproducing these dynamics in the future through collaborative instrument personalization could be a very profitable advantage of our system on a therapeutic level.

Moreover, Michel was able to use this participative organization to alleviate most of the undesirable effects of our experiments. Indeed, introducing something new in the protocol, whatever it may be, is always complicated with children who have trouble controlling their behavior and can quickly become overwhelmed by the excitement that novelty is bound to induce. We expected quite a lot of agitation when we introduced MAWii and indeed started a miniature protest of impatient children at the door of the music therapy room after one patient started running around telling all the others that Michel had brought a Wii.

However, as they were asked to actively participate in the project and were explicitly associated with its success or failure, they felt responsible and, after this initial incident, managed to control themselves to a surprising extent. Michel thus was able not only to calmly introduce an object which, in other conditions, could easily have created an unmanageable situation, but also to gather extremely valuable feedback which helped us a great deal afterwards.

6.2.3 Behavioral Impact

As with more or less any other kind of pathology, increased motivation makes the treatment more efficient. First, it encourages the children to formulate projects and plan ahead, something which they often have a lot of trouble doing due to their pathologies. Indeed, even several months after the first experiment, which took place in May 2008, the children kept on talking about it and were very excited when they were told, in October 2008, that the Wii would be back and they could use it every week this year. One of the most challenged patients with regard to making projects even came to Michel during the after-school snack to ask for a playing slot saying: "Can we come for the Wii today with P.? We discussed this last Friday". This long term projection surprised the whole team and was interpreted as a sign of great progress.

Second, better commitment to the treatment helps to deal with the various problems that may arise during sessions. The children did show a lot of excitement about the system, which was not necessarily good for a therapy intended to help them to improve self-control. However our experiments proved that, thanks to their increased motivation, they were more able to focus and control this excitement properly. This was especially apparent when the system had to be restarted in the middle of a session. Instead of losing interest, the children were actually worried that they might have broken something and remained very calm while Michel reconfigured everything from scratch, which took about 3 minutes. Although it is impossible to say with certainty that their behavior would not have been the same in a similar situation involving normal instruments, we can at least conclude that MAWii has enough motivational power to, in Michel's own words, "make [the children's] symptoms disappear for these three minutes", something which does not happen too often and is, in any case, a major achievement.

6.3 Psychodynamical Aspects

Several characteristics of our system, such as the plastic feel of the Wiimotes, have a specific psychodynamic impact that, good or bad, is at least very different from that of real instruments. However our results suggest that these differences do not prevent elaboration and that they even participate in making the system a mediation object at least as efficient as traditional instruments.

6.3.1 Corporality

The biggest a priori objection from the music therapy community was that, due to their lack of physical presence in terms of size, texture, vibration etc., Wiimotes would not induce any useful emotional response. This is clearly not true: as explained in Section 6.2.1, the children quickly projected themselves into positive role models such as musicians on TV, but also made more abstract, symbolic remarks like "I'm playing a beating heart" or "It sounds like it's running". These utterances and many others alike show that our system does indeed retain enough evocative power to trigger meaningful elaboration and symbolization in our patient population.

Moreover, MAWii, thanks to its efficient filtering algorithms, offers much more freedom of motion, which the children made use of in several ways. Some got up and danced to the music while playing, which is impossible with most real instruments, resulting in much better immersion. Also, MAWii gave them the ability to move around the room while playing, which adds an important new dimension to group interaction, as positions in the room are no longer predetermined by the choice of seats. Therefore with MAWii we have, just like in SoundBeam (See Chapter 2), begun to establish a bridge between music and dance/corporal expression therapy, which should progressively enable therapists to treat an even wider range of disorders, notably those involving spatial awareness and orientation.

Finally, other children started mimicking the gestures associated with the guitar sounds they were using, even though the percussion-like triggering mechanism, which had not been altered, did not suggest this kind of manipulation at all. This shows that just like players usually quickly discover that they need not make any large movements when pitching in a game of *Wii Baseball* [32], the incomplete motion-sensing capabilities of the Wiimote make it possible to play with MAWii in ways we did not expect at all in the beginning, guitar-like strumming being only one example.

Of course in both cases realism suffers, but this does not seem to matter to players, especially since neither *Wii Baseball* nor MAWii were very realistic to begin with. Moreover, in both cases the players' unconventional approach serves the purpose of the game: wrist-only play makes *Wii Baseball* more challenging, as it enables players to play in their back to hide their moves, and guitar gestures result in better immersion, showing that the children are able to symbolically compensate for whatever lack of corporality the Wiimotes might suffer from.

Just as our system does not intend to rival traditional instruments in terms of musical expressiveness, since we favor ease of use instead, we do not aim at achieving the same richness of haptic and visual feedback. Indeed, our results show that, although it is certainly a strength of traditional instruments, such complex feedback is not mandatory for the system to work properly as a mediation object. Therefore, we feel justified in investigating the impact of the new features MAWii offers, including but not limited to its new, freer approach to space and symbolization, which largely result from its high level of abstraction.

6.3.2 Identity

Every time we used the system, even for informal tests with colleagues and "normal" children, users were concerned because they were not able to distinguish their own sounds from those of others. Indeed, the Wiimotes all look alike and all the music comes out of the same distant speakers, sometimes making it very hard to know who is playing what, in particular when everyone is using the same instrument. This issue is especially crucial with our population, as an important part of Michel's method revolves around the concept of sameness and difference[4].

Regarding the look of the Wiimotes, we added blue, red and green color stickers to distinguish between the three pairs of Wiimotes available, and have had no complaints since then, which shows how even very little individuation can have a lot of impact. We have not noticed any significant variation of the children's behavior with respect to which of the three colors they were assigned but remain careful regarding this matter as it has been

[4]For example, during an improvisation, children must realize that other players, instead of being the same entity as them and therefore being bound to their will, are different people with their own freedom of choice, but are also the same as them in the sense that they can communicate with and understand each other and are equally important in the construction of the musical dialog that is taking place.

shown that, for example, martial arts contestants dressed in red are more likely to be perceived to dominate the match than their blue opponents, even by professional judges [130]. Switching to colors with less perceptive and emotional impact such as light pastels might be the safest bet, even though children do prefer strong colors such as bright red or green. In any case our results prove that the clear differences in shape, textures and so on that traditional instruments boast are not necessary for efficient therapy.

In the sound domain however, things remain complicated. The children often all chose the same instrument, making improvisations difficult even for Michel to follow. They expressed their anxiety about their inability to recognize their own productions during sessions, but also found a classical solution: they stopped by themselves without prompting from the therapist and started again, one by one. Composers of intricate pieces such as fugues often use this technique to help the listener, introducing each layer separately to make it easy to grasp. This method of isolating each input, although it seems simple, is not at all straightforward for children of such ages, as explained in [131]. Once more, this shows that the children are able to compensate for their apparent loss of identity, which may thus turn into an advantage, since it can greatly encourage complex collaborative group processes such as those described above.

6.3.3 Sonorous Exploration

With our system, the children get access to sounds they could never produce with real instruments, which would either be too big, too expensive or too hard to play; this is very interesting from a psychodynamic point of view. Indeed, some instruments carry a very strong cultural and emotional meaning. For instance the guitar, which was chosen most often, is clearly associated with stardom and the overall positive social value of musicianship and the "atmospheric ambient" sound, a somewhat eerie artificial sound chosen by six children out of eight on one day, has a powerful evocative power revolving around tension and fear. Our system makes it possible to build upon these associations to enhance mediation by offering many more sonorous universes and, consequently, more emotional responses than would be possible with traditional instruments.

The best example of this is the one day mentioned above when almost all of the children in the three sessions that took place on that day chose the atmospheric ambient sound[5]. In all three groups, the "atmo" started a lot of discussion about fear, and more specifically about scaring someone, for real or as a joke. This association with fear probably is not inherent to the nature of the sound itself and is much more likely to be the result of the children's high exposure to TV and movies where such indefinite sounds, with

[5]This is unlikely to be a coincidence since the door remains open during the sessions and the children outside can hear what is going on.

an unclear attack and a highly non-harmonic spectrum, are often used to underline tension and suspense. Nevertheless, this clearly shows how a specific sound available only with our system may trigger a powerful group mediation process that helped the participants talk extensively about potentially traumatic things they had rarely discussed before.

This makes the case for a system able to produce any kind of sound, going far beyond the "musical" ones that are used in most contemporary music, be it pop, jazz, rock, classical music or just about anything else. Our system can use animal sounds such as a dog's bark, domestic sounds such as glass breaking or even human sounds such as flatulences which, although they are taboo in our grown up world, have proven very useful with children in multiple therapeutic situations [49]. These concrete sounds, named this way in reference to Schaeffer's *Musique Concrète*, open up an entire world of previously untouched associations and should, in our opinion, play a significant role in instrument personalization.

Chapter 7

Conclusion and Directions for Future Research

Using an incremental methodology inspired from Action Research, we have designed and tested MAWii, our Wiimote-based system for active, analytical music therapy, in a real clinical setting. We have demonstrated that using only cheap, low-end technology, it is possible to create a full-blown session management and musical performance system viable as a complement or even as an alternative to traditional instruments, at least for improvisational music therapy with children suffering from behavioral disorders. In this conclusion chapter, we first summarize the evidence that supports the previous claim. Then, we finish the presentation of this case study by discussing the numerous opportunities for enhancement of traditional music therapy that our system offers. Indeed, now that we have proven that a video game controller-based system such as MAWii can be as good a mediation object as usual instruments, we intend to pursue future research in two specific directions which we find promising, namely customization and data analysis.

7.1 A Successful Mediation Object

Our work with Michel was very exploratory, since to our knowledge no other project has blended active music therapy and video games as we did. Given the persistent skepticism of a large part of the French music therapy community regarding MAWii's viability as an equivalent for traditional instrument, our goal was not to outperform traditional instruments, but simply to prove that it was indeed possible and potentially beneficial to integrate a video game-based system into a classical treatment protocol. We think we have reached that goal and summarize here the evidence showing that we have created a practical tool with strong motivational and psychodynamic effects.

7.1.1 A Practical Design

We have met our requirements in terms of usability with respect to three main criteria:

- A MAWii system is robust enough to be used weekly in a rather unfavorable clinical environment where technicians are forbidden to enter the premises and therapists barely have five minutes to prepare their activities. In addition, it can be put together for under $1000, or even much less if the computer and loudspeakers are already available.

- Our tool easily integrates within Michel's existing protocol. Although it is still an early prototype, its operation is extremely simple and requires very little attention from the therapist during the session. It is therefore transparent enough to be used even with very impulsive patients who would undoubtedly become unmanageable if their therapist was unable to devote his or her full attention to them.

- The percussion-like triggering mechanism we devised is very intuitive: even the most challenged children were able to have fun instantly with our system. Furthermore, most testers showed sustained interest and were roughly equally attracted to traditional and electronic instruments, with many groups using the two together. This proves that MAWii is indeed easy to use and hard to master as we intended it to be.

We think that thanks to these characteristics MAWii qualifies as a true music therapy tool suitable for use with agitated patients by non tech-savvy therapists in even the most rigid clinical environments.

7.1.2 An Efficient Motivator

Like virtually all serious games, one of the main goals of MAWii, if not the single most important one, was to significantly increase at least some of the patients' motivation for the treatment. We achieved this by relying on four specific motivational assets:

- The Wiimotes carry a video game-like aura of fun which is a great motivator for children who often do not have access to this kind of technology. They get the chance to remedy the frustration they frequently develop because of their strong exposure to both Nintendo's advertisement and peer pressure at school.

- Computer-assisted playing makes it possible for the children to use beloved sounds that they never would have been able to produce with a real instrument. This illusion of mastery gives them access to the great social value of musicianship without any training.

- The system's many features, notably the large and diverse collection of sounds it makes available, as well as the richness of its control scheme, which leaves a lot of room for progress, encourage curiosity and maintain interest.

- Our patient-centered, Action Research-like protocol empowers the children by putting them in the center of attention and actually taking their suggestions into account. Although this research process obviously cannot be reproduced as is in the future, we think the same kind of motivating dynamic can be achieved through personalization, as we explain in Section 7.2.

Our hope is that these four motivational levers, which are specific to our system, will both enhance commitment for those who are already being treated with music therapy and appeal to otherwise uninterested or skeptical patients through their attraction for video games.

7.1.3 A Psychodynamically Active Tool

The point of mediation therapy is to help elaboration and association with an object or activity that acts as a support for symbolization and as a bridge between patient and therapist, reaching into the subconscious. We have demonstrated that Wiimotes can be efficient mediation objects thanks to three distinct processes that compensate for their artificial, plastic feel and rather unmoving appearance compared to real instruments:

- The children are very imaginative and have no trouble building symbolic representations on top of even the blandest objects, be it wood sticks or cardboard tubes. Therefore, as we have shown, they have no trouble at all doing so with the Wiimotes. Moreover, the freedom of movement these new controllers offer gives them the ability to approach space in an entirely new way through dancing and innovative gestures which contribute to immersion and therefore to symbolization and elaboration.

- The potentially troubling confusion of identities that results from the production of all of the sounds through just one pair of speakers, thereby preventing any kind of realistic audio spatialization, turns out to be very interesting when working with children on the notions of sameness and difference. Indeed, while the various shapes and textures of real instruments impose some kind of organizational structure on the group even before a single note is played, from a physical point of view all the Wiimotes look and work the same apart from their colors, making all of the players strictly equal in this respect. This forces them to form plans and strategies to properly assert their own identity through abstract and symbolic means in the sonorous world.

- By considerably widening the spectrum of potentially usable sounds, MAWii compensates for its lack of expressiveness compared to real instruments. It gives therapists the possibility to use culturally relevant instruments that they could never buy, synthetic sounds with evocative characteristics otherwise difficult or impossible to reproduce and even concrete sounds from everyday life. These three new categories of sounds open up a new space for sonorous exploration and can foster elaboration on previously untouched topics through novel associations and symbolizations that real instruments would be unlikely to mediate.

With these results, not only do we show that MAWii retains more than enough evocative power to trigger meaningful emotional responses, we also demonstrate that in certain situations the extra capabilities offered by our system can give it the power to trigger several previously inaccessible psychodynamic processes. This gives MAWii a strong potential to be a tipping point in the treatment of a large number of patients who, for example, have yet to find their *ferryman sound*.

7.2 Customization

Ever more flexible and customizable devices, culminating with tactile, motion-sensing or even controller-less interfaces, can reshape their virtual control surfaces and volumes at will to offer highly configurable and context-dependent interaction schemes. For example, an Apple iPad only displays a keyboard when users click a text field while an Oblong Technologies G-Speak [132] can assign any hand gesture to any command for a very natural and user-specific interaction. Furthermore, this dynamic of personalization also permeates the social sphere, as a given individuals's online identity becomes more and more fragmented across multiple platforms, each with their fully customizable profiles and avatars, be it social media, networking or gaming sites and applications.

We want to take advantage of this enthusiasm for personalization in our system. Here, we explain how we plan to add new, user-specific features and integrate them into an avatar instrument for each patient, in order to recreate the empowering and motivating dynamic we started with our test population by putting them at the center of the design process.

7.2.1 New Capabilities

As in most video games, we plan to reward players who reach a given level of mastery with new capabilities and sounds to keep their interest high. We made a first attempt at this with the addition of an extra instrument for children who had already tried the system 3 or 4 times. For their first attempt, all of them switched repeatedly and did not make much controlled use of the new feature, even though they had already mastered the basic gameplay of MAWii. We think this is due to the fact that the notion of having two different types of buttons was hard to grasp on the first time and that they simply did not understand or even listen to their therapist's explanations.

Only two children tried this new feature for more than two sessions, so that not much can be said with certainty, but they did show a continuous slowing down of their switching rate, both changing instruments only once in their last session. We interpret this as evidence that the system's behavior was progressively understood, ending with a clear identification of the effect of all of the buttons. However at the same time this shows that the feature, once it is properly acknowledged, is seldom used, most likely because it creates too much of a sonorous rupture which neither of the children were willing to take responsibility for. This means that multiple instruments, although a viable and valuable addition, might need to be implemented in a better, more intuitive way and, more importantly, should be considered only for the most advanced players who wish to play with radical musical tensions.

There is room for a more progressive enrichment of the gameplay which could appeal to intermediate players. The one idea we would like to try first is the addition of sound effects. Many kids, especially boys, are very fond of the heavy effects that popular rock guitarists have been keen on using since Hendrix made them mainstream during the 1960's. We intend to assign such effects to strokes on the left-right and forward-backward axes, which are currently unused. We think this should be (1) more intuitive, as it does not require to distinguish between two conceptually different kinds of buttons and (2) less intimidating, as adding effects does not create as abrupt a rupture as changing instruments.For example, a forward stroke with A pressed will simply produce sound 3 with an added fuzz effect, which turned out to be very popular during informal testing.

Further in the future, an interesting development would be the integration of the Wiimote Plus to create new, more complex gestures or, more practically, custom controls for disabled children who may have trouble with our percussion-like scheme. However, adding this kind of feature is far from easy and even quite risky as it might confuse players. Consequently our first focus will be sonorous and visual customization, which have proven to be great motivators in many other contexts such as MMORPGs.

7.2.2 Avatar Instruments

Involving children in the creation of an object they are going to use is an almost sure-fire way to keep them interested and motivated. It is very common in many contexts: recreational, such as making water balloon slings or building a shelter in the woods; educational, such as constructing a thermometer or light sensor to make some measurements in a physics experiment; or even with a creative purpose, for example making costumes for a show or play. Understandably, despite its many positive effects this method has rarely been used in music therapy. Indeed, making musical instruments is almost always very complicated, as even the simplest of shakers requires precise carving to obtain a good sound.

With a tool like MAWii however, personal instruments for each user can be created very easily. Firstly, we will encourage patients to choose a name, a picture and the sounds they want to use for their characters. We think this, in itself, should be a very good way to have children elaborate on their personal issues, as in creating their instrument they will most certainly reveal clues about the tensions between their perceived and actual self that will prove useful for the therapist who witnesses the process. This way, in addition to enhancing motivation and encouraging planning, we would obtain a new, more interactive version of the psycho-musical assessment [54] in the form of an avatar instrument incarnating each child's sonorous history.

We think it could be very interesting to push this project even further and have the children actually record the sounds they want to use with their avatar and maybe choose the gestures that trigger them from a pool of available movements. Then, we would not create mere avatars but actual sonorous *alter egos*. They would add a very interesting twist: giving them the name of their creator and making them available for all the patients to play with would introduce a new type of tension in terms of identity inside the group. From a symbolic point of view, dealing with the perspective of letting others play with your creation and *alter ego* would surely trigger some very meaningful responses. Furthermore, while an avatar is not necessarily a mirror of the self and can be created with a specific goal in mind, such as making an instrument with only tribal sounds, creating the kind of personal instrument we describe here would take much more dedication and, in addition to engaging planning abilities even further, is likely to much better reveal the overall personality of the children.

7.2.3 Empowering Process

Our Action Research methodology proved to be very efficient in raising the children's self-esteem and motivation for their treatment. Using personalization, we hope to continue to leverage the many positive benefits of the process of patient-centric design outside of a research context. Therefore, we want to provide efficient customization tools so that any therapist can easily engage in this creation dynamic with his or her patients even without any technical knowledge.

First, creating their avatar and watching it evolve and get new capabilities through the gathering of experience points should prove to be a very good motivator, provided that the patients in our target population are anything like the players of the most popular MMORPGs, which largely rely on this leveling and skill acquisition scheme. This will directly put the children in a planning dynamic and hopefully widen their temporal horizon as, by looking at the experience points acquired, they will both be reminded of their progress and given goals such as reaching the next level or getting the next additional capability or sound.

Second, creating alter ego instruments for everyone to use could have a very strong impact on self-esteem. Instead of seeing themselves as disabled patients, the children would hopefully come to see themselves as creators whose opinions are valued enough for their vision of music itself to be embodied into an instrument bearing their name. Furthermore, recording the sounds themselves would put them in the position of a successful producer or instrument-maker, two role models potentially just as efficient as that of the musician.

7.3 Discussion on Data Analysis

One of the central motivations behind using MIDI instruments and computer systems in general to support improvisation sessions is our will to help develop evidence-based methods in music therapy. With MAWii, we recorded a substantial amount of MIDI data which we tried to analyze automatically. It turns that even though we did compute some interesting figures from our MIDI recordings through very simple statistical processing, we have not been able to extract the more abstract, higher-level kind of information we were hoping for in terms of synchrony rating and segmentation.

Here, we discuss the numerous advantages of designing this kind of capabilities in our systems and the issues that make these tasks complex enough to remain impossible for even the best algorithms, before providing clues as to what may be done to move forward. We conclude by focusing on visualization which, even though it is not an information retrieval method *per se*, is most likely the one thing that music therapy practitioners will actually benefit from, at least before music therapy expert systems become much better at extracting patterns and structures from MIDI data.

7.3.1 Synchrony

Michel's work is centered around his patients' perception of rhythm and time in general. We explained that one of the most important conclusions of his Ph.D. research was that impulsive children were more likely to build symbolic representations and communicate with rhythm than with other components of the music. This claim is supported by the comparatively larger number of pauses asked for during replay to comment and elaborate on rhythmic events, be it the establishment of a simple common pulse or the development of a more complex call-and-response pattern.

We hoped to be able to compute quantitative measurements of synchrony from our MIDI files to further investigate this phenomenon and see whether a better degree of synchrony correlates with more numerous and meaningful elaborations. However, what we saw as a simple task at first turned out to be extremely difficult. Even though many very efficient algorithms exist to measure the tempo of a piece from a raw audio recording, they only work properly with music that may be complex but does not have too many off-beat, unpredictable accents, such as rock, techno or even J.S. Bach's music, as long as the tempo is more or less constant. When used on a more syncopated style like jazz or funk, these algorithms do not work as well, although some still perform with a success rate around 80% [133]. Even if that is already quite an achievement, one incorrect evaluation out of every five seems a bit too much for clinical applications.

The real problem nevertheless lies somewhere else. Contrarily to professional musicians using performance-oriented instruments, impulsive children using MAWii produce rather chaotic and imprecise improvisations where the common pulses that could be detected by the trained ear of a therapist are fuzzy at best. This has made it impossible to compute reliable tempo estimations from the data we gathered, at least with the simple, generic methods we tried[1]. All the algorithms we designed quickly got confused by the missing or inaccurate beats that the human brain seems to have so little trouble correcting to detect the right pulse.

This highlights the necessity to design a custom algorithm for this task, which would require a lot of work and probably would have to include statistical learning steps instead of relying solely on direct methods, as the approaches we tried do. However we believe that obtaining such an estimator for synchrony would be well worth the effort, as it could be used to grade the improvisations automatically and give patients a sort of *communication score* which would undoubtedly encourage them to cooperate more during their performances.

7.3.2 Segmentation

Analyzing session recordings is a very tedious task: therapists have to listen to ten-minute long improvisations multiple times, focusing their attention on specific players and features. Like we said in Section 5.3.5, careful *a posteriori* analysis is consequently almost only practiced by researchers who seek a specific answer. In the clinical world, therapists have no time to dedicate to this process, even though they usually recognize that it would provide them with very valuable information. We think MIDI recordings and computational musicology tools could change this by significantly speeding

[1]In addition to the tempo estimation functions included in the MTTB, we tried various combinations of basic wavelet transforms and displacement/deletion algorithms according to multiple references pulses

things up, even though we have up to now been unable to devise algorithms powerful enough to extract the structural information we were targeting.

In [17], Lecourt defines several categories of patterns or structures that recur in *Sonorous Communication* sessions, such as scrambling[2] or hammering[3]. She considers these features as meaningful segmentation blocks, even though their interpretation can vary greatly from one improvisation to another. For example, scrambling is defined as a sudden rupture from the current mood or pulse with everyone playing frantically and chaotically until a new stable situation emerges. It is easy to see that such an event can be considered negative, when it marks a failure to sustain an interesting collaborative effort, or positive when it enables a group stuck into a given schema to move on to another pattern or style if it cannot transition smoothly.

In any case, being able to detect these structural events would be very interesting as it would enable us to create some kind of outline of the improvisation. We envision bookmarks that therapists could directly jump to when replaying the recording to analyze it, dramatically speeding up the task and allowing them to focus on interpretation instead of annotation. Furthermore, they would then be able to provide quantitative results, for example rating a patient's or a group's progress according to the number of positive and negative processes that occur. This way, they would quickly obtain tables akin to those painstakingly filled by Michel for his research after hundreds of hours of careful analysis, which enable him to prove the efficacy of his method beyond any reasonable doubt. However, such a tool is still years of hard work away. First, the theoretical definition of the structures to detect is still too fuzzy and does not easily translate into measurable quantities. Second, generic music information retrieval tools are not adapted to this task, which would at least require the design of a dedicated filtering algorithm taking into account the poor technical skills of the players.

Given the very high complexity of structure extraction, we think a good first step would be segmentation according to patient investment. Some simple yet interesting parameters such as mean volume and note density can already be computed with the MTTB, as we explained in Chapter 2. However, even though they correlate quite well with patient dedication, which is very relevant for therapists, they have two major flaws. First, no definite measure of player dedication weighting the influence of these two parameters has been validated. Second, the results published in [64] only apply to duo sessions and would have to be validated for groups, where player focus would probably manifest itself a bit differently. For example, reckless, chaotic playing, which makes mean volume and note density skyrocket, is often used as a defense mechanism in these groups, contrarily to duo sessions where therapists work precisely to prevent these defensive processes

[2] *Brouillage*, in French
[3] *Martèlement*, in French

Figure 7.1: A typical polyphonic piano roll view.

from happening.

7.3.3 Visualization

Thanks to the inherently abstract and multitrack nature of MIDI, it is very easy to create powerful representations that focus on a given aspect such as pitch, volume or note length. One of the most commonly used visualizations for MIDI files is the so-called *piano roll* graph (see Figure 7.1) which has now become a standard for most if not all MIDI sequencers. It enables the viewer to instantly capture various features of the musical piece being analyzed such as highly polyphonic or solo parts, dense or sparse note patterns, high or low ambitus etc.

As we said in Section 5.1, this is very interesting because it enables therapists to capture a lot of the structure of the improvisation at a glance without even listening to it. By synchronizing multitrack MIDI files with a stereo audio recording, something which is done automatically in all modern DAWs, it becomes easy to jump from point to point in the improvisation to focus the analysis on specific, meaningful moments. Moreover, if many players are active at the same time, it can become extremely difficult to figure out what each of them is playing. The piano roll visualization eases this task by giving clues about the rhythmic patterns or melodic contours to listen for.

However piano roll was designed for MIDI composing and editing, not for precise analysis, be it by music therapists or anyone else. Therefore it seems natural to look for other, more specific visualizations that emphasize other therapeutically relevant aspects or structures. This is what the MT LogBook does with its cross-correlogram, which can for example show rather explicitly if one participant is following or imitating another. We intend to apply the methodology we used to design MAWii to incrementally create powerful, therapy-oriented visualization tools by working very closely with therapists testing the production release of MAWii, currently under development at MINES ParisTech.

Part III

Second Case Study: A Music Game for Demented Patients

In this second case study, we continue with the same approach: given the surprising success of Nintendo's Wii with the elderly [134], we borrow techniques and off-the-shelf components from the world of video games to empower healthcare practitioners with a low-cost yet versatile music therapy tool. MINWii, where patients use Wiimotes to either improvise music or play predefined songs on a virtual keyboard displayed on screen, is the result of a close collaboration with Dr. Renaud Péquignot, a gerontologist at Saint-Maurice Hospital in Charenton, in the suburbs of Paris. He co-authored the paper from which some of the text of this part was adapted [135].

Relying on Dr. Péquignot's expertise, we took the specific features of Alzheimer's disease into account to create a first prototype of the game and test its core mechanics. We then performed a qualitative, small scale test in a therapeutic environment to iteratively improve our design. Once we considered the gameplay mature enough, we conducted a quantitative usability and satisfaction study at Broca Hospital in Paris as a preliminary for a large-scale therapeutic assessment. This was done in collaboration with Sandra Boefsplug and Mélodie Boulay, under the supervision of Pr. Anne-Sophie Rigaud, who are all co-authors on the paper, currently under review, from which most of the statistics in this part were taken.

To present our research, we first briefly talk about dementia, its symptoms, treatments and impact on patients' life and society as a whole. We then explain how we implemented our incremental design protocol and expose the promising results we obtained, in terms of usability, fun and socialization support. Finally, we conclude with a summary of MINWii's contributions and a review of our future work with this system, notably therapeutic validation and large-scale diffusion.

Chapter 8

Context

According to Alzheimer's Disease International [136], more than 35 million people worldwide suffer from Alzheimer's disease, the most common form of dementia. Researchers estimate that this pandemic may easily escalate to affect more than 100 million people in 2050, approximately 70% of whom in developed countries. Caring for so many dependent patients already costs trillions of dollars annually [136], and remains rather uneffective. Indeed, the best that current drugs can do, in most cases, is to slightly slow down cognitive decline. Consequently, until satisfying treatment methods are found, our aging societies will have to adapt and attend to the needs of an ever-growing number of demented patients. Non-pharmaceutical approaches can help with this issue, something that many health agencies throughout the world have now acknowledged [137],[138]. Among these alternative treatments, two techniques seem to stand out [139]: Cognitive Stimulation Therapy (CST) [140] and the one of interest here, namely Music Therapy (MT).

To better understand the implications of this dementia epidemic and the role music therapy has to play in it, we begin this introduction chapter by quickly reviewing the multiple conditions that dementia designates, with a focus on the most prevalent, Alzheimer's Disease. Then, we examine the various non-pharmacological approaches that are used in the treatment of these illnesses, of which music therapy is just one facet. Finally, we focus on patients' well-being, the one aspect that we hope to influence in order to have a lasting impact on the management of dementia.

8.1 Dementia and Alzheimer's Disease

Alzheimer's disease is the most prevalent and, consequently, the most studied type of dementia. Several other kinds exist, such as vascular or mixed dementia, but their symptoms are more or less similar so that, for our purposes at least, distinguishing between these anatomically very different illnesses is not really necessary. Consequently, this section simply starts by covering the main symptoms of dementia in general. We then give a brief overview of the measurement scales that are commonly used to monitor the evolution of demented patients and conclude with a focus on home stay and its impact on patients' life and society as a whole.

8.1.1 Symptoms

Although a lot of research on the subject is going on, we still understand rather little of how Alzheimer's disease (AD) operates from a physiological point of view. Furthermore, our work targets dementia as a whole, which can have a great many causes besides AD. For these reasons this section only examines the cognitive symptoms of dementia and the behavioral issues they induce. Interested readers can refer to [141] for an in-depth analysis of the neurological factors of dementia.

Cognitive Symptoms

Alzheimer's disease is well-known to affect memory quite drastically. However, it is sadly far from being the only function impaired by dementia. There are in fact three main areas in which patients' cognitive abilities are impaired, to very variable degrees:

1. **Memory**: Patients' working memory tends to weaken drastically, some of them becoming unable to recall the title of the book they were reading no longer than two minutes prior. Also, recent memories tend to disappear first, with childhood recollection remaining surprisingly easy in comparison. Music clearly has immense power in this area (see Section 10.2).

2. **Attention**: Demented patients often have trouble focusing on a task for an extended period of time as they are very easily distracted. Therefore, they may examine the same image or sound over and over, seemingly discovering it every time. In particular, their visual attention impairments make it difficult for them to follow fast-changing images.

3. **Execution**: Planning and executing the sequential steps of a long task is very difficult for demented patients. They often have trouble determining what to do in what order, even though they are perfectly able to accomplish all the required sub-tasks. In the first stages of dementia, it can be that, if they are interrupted in the middle of what they are doing, they become completely lost and unable to pick up where they left, even though without disturbance they would have achieved their goal. Further into the disease, they also may simply plan things in the wrong order if they are not properly supervised, for example catching a cold by going out to get the mail before even getting dressed.

These multiple cognitive deficits lead to complex behavioral consequences which are not always very well understood, but in any case put a lot of burden on the shoulders of the patients' caregivers, who have to clean up behind them.

Behavioral Issues

For our purposes, we distinguish between four broad aspects of dementia-related behavioral issues:

1. **Depression and apathy**: Many patients are very well aware that their abilities are diminished, as they stumble on every day life tasks that they used to carry out without even thinking about it. This, added to the sadly extremely frequent loneliness they experience, either at home or in institutions, often amounts to moderate or even severe depression. In the worst cases, patients become apathetic and seem to care about absolutely nothing. They then refuse to participate in any activity, either for fear of failing or simply because they are just too sad and do not expect anything to make them feel better.

2. **Anxiety and agitation**: Because of their inability to cope with everyday tasks such as driving or cooking, demented patients can become very anxious. Indeed, they realize that if anything goes wrong, or if their caregivers let them down, they will not be able to go through their day on their own. This anxiety leads to agitation and restlessness, with patients for example constantly leaving their room to look for their children because they think that they are going to visit and come reassure them.

3. **Disorientation and wandering**: Part of the MMS test (see below) consists in asking patients where they are, what the date is etc. to see if they are aware of their environment. As easy as this task may appear, it can become surprisingly difficult to accomplish even for patients who otherwise seem to be in command of their behavior. At its peak, complete disorientation can lead to wandering: patients start walking aimlessly and endlessly around their institution, which can quickly become problematic. Thus, specialized facilities have to be built with that in mind, with either circular corridors where they can wander freely or, on the contrary, short corridors which always lead to a communal area such as the animation room where they can quickly be picked up by staff and taken back to their room.

4. **Executive deficits**: Because they are unable to plan their actions properly, demented patients often cannot accomplish complex tasks such as cooking a full meal or cleaning the house. For some of them, this is not so much of a problem since they are properly assisted, often

with someone at their side at all times to take care of everyday tasks. A large majority however do not have access to such quality care and spend their days alone at home. It is then up to their often exhausted caregivers to clean the mess they have made by trying to tidy up but forgetting to put things back in the cupboards or going in their shower with their clothes on.

Although it is not easy to significantly reduce these behavioral manifestations of dementia, we think that, by adapting their environment and offering them suitable activities, it is possible to give patients the opportunity to continue to enjoy their life much further into the illness than they usually do today.

8.1.2 Evaluation of dementia

Dementia is an extremely pervasive disease. It affects almost every aspect of patients' life in one way or another, be it their performance in everyday tasks, their social interactions or their perceived self. Therefore, healthcare practitioners need a wide variety of tools to assess the level and impacts of dementia, which can vary greatly from patient to patient. Here, we describe two generic ones that are relevant to our approach: MMSE and QOL-AD.

Mini Mental State Evaluation

The Mini Mental State Evaluation (MMSE or MMS) [142] is used by physicians and psychologists to evaluate patients' overall level of impairment. It consists of 8 categories of questions, which amount to a total of 30 points:

1. **Orientation to time**: Year, month, day etc., from broad to narrow.
2. **Orientation to place**: Country, city, street etc., from broad to narrow.
3. **Registration**: Repeating three named objects.
4. **Attention and calculation**: Serial sevens, i.e. counting down from 100 by increments of 7.
5. **Recall**: Recalling the items from the registration steps.
6. **Language**: Naming a watch and a pen.
7. **Repetition**: Repeating a sentence.
8. **Complex commands**: Variable, but drawing a complex shape is often used.

Several flaws of this test have been identified, but it remains reliable enough and, most importantly, fast enough to administrate for physicians to rely on it as their primary screening and assessment instrument. A score over 25 or 28, depending on the sources, is considered normal. Between 21 and 25 corresponds to mild impairment, 10 to 20 is said to be moderate and below 10 is considered severe.

Quality of life in dementia

The QOL-AD is a brief, 13-item scale designed specifically to obtain a rating of a patient's quality of life from both herself and her caregiver. It uses simple and straightforward language and responses and includes assessments of the individual's relationships with friends and family, concerns about finances, physical condition, mood, and an overall assessment of life quality.

Caregivers complete the scale as a questionnaire about their patients' QOL, while patients complete it in an interview format. The 13 items are rated on a four-point scale, 1 being poor and 4 being excellent; total scores thus range from 13 to 52. It generally takes caregivers about 5 minutes to complete the measure while for patients the interview usually lasts about 10 to 15 minutes. Those with an MMS scores of 10 or higher can usually complete it with no problem; below that physicians usually rely on the caregiver's answers only.

Again, this test is widely used because it is practical and quick to administer. It is complementary to the MMS score, as it gives a good assessment of the impact of dementia on patients' lives. Indeed, such an impact varies greatly from one subject to another as proper care can make life with advanced dementia much easier and enjoyable than life with a very mild cognitive impairment but in an unadapted environment.

Improving quality of life, especially where it is the poorest for demented patients, is exactly what we hope to do with the MINWii project: even though dementia remains incurable and patients' decline thus unstoppable, we believe that we can make their life significantly better overall by offering them adapted activities that, among other things, are enjoyable and improve their self-esteem.

8.1.3 Home Stay and Behavioral Issues

Of course, developing cures for dementia and better adapting the specialized institutions in which patients are, for now, bound to end up is crucial and is part of our objectives. However, the one aspect that we see as the most important for our approach is facilitating home stay. Indeed, in spite of their age-related motor and cognitive deficiencies, a large part of dementia sufferers are healthy enough to stay at home: they do not need heavy life-support apparatus nor constant assistance for simple tasks such as going to the toilets. Therefore they could conceivably make do with minimal daily care such as food delivery and help for personal hygiene. This would have great benefits in terms of cost: a visit from a nurse and a few hours of help from a personal assistant every day cost roughly half as much as a permanent stay in a caring home and almost three times less than a stay at the hospital.

However, their behavioral issues (see Section 8.1.1) often cause them to be sent to specialized institutions in spite of their relatively good health. Indeed, left alone at home, they may quickly exhaust their caregivers by messing up their place or, worse, jeopardize their own safety and that of others by imprudence, for example by forgetting to turn the oven off. Episodes of this kind eventually lead their family to give up and send them to a hospital or an institution, where they find an adapted, safer environment and can be watched over constantly.

However, not only do institutionalized patients cost much more to society, they are also significantly more likely to be depressed and die faster [143] than those kept at home. Indeed, it seems obvious that demented patients, in the large majority of cases, wish to stay at home. First, they feel secure at their own place because they know where things are, whereas learning the geography and inner workings of a new institution can be difficult and is usually quite stressful. Second, they frequently, and with reasons, interpret their placement in an institution as a sign that they have become an unbearable burden for their family. They almost always feel useless and abandoned, no matter how much effort their new caregivers put into making them feel safe and at home. Finally, institutionalized patients miss social interactions, as they get even fewer visits than before, and often report this lack as a major cause of their suffering.

Hence the utmost importance of finding ways to reduce behavioral issues in demented patients to keep them at home for as long as possible: home care is a win-win situation, as it makes for significantly happier patients and is far less of a financial burden for society.

8.2 Non-Pharmacological Approaches

A few drugs exist that have a statistically significant impact on the progression of Alzheimer's disease, such as donepezil [144]. However, their effects remain very limited and they are far from preventing the loss of cognitive abilities; at best can they temporarily stabilize or slightly improve some of the patients' cognitive abilities. In fact, their power seems to be more or less on par with that of proper non-pharmacological treatments, which tend to cost less and have fewer harmful side-effects, if any at all [145]. Consequently, an increasing number of health agencies now clearly advocate extensive use of non-pharmacological approaches in combination or even sometimes instead of drug-based treatment [137].

To better understand the role that music therapy can play in such a context, we first give a quick overview of the multiple techniques that are used in the treatment of dementia. Then, we focus on the two approaches that seem to be the most effective: cognitive stimulation therapy and music therapy.

8.2.1 Overview

Different healthcare practitioners advocate a wide variety of methods for the non-pharmacological treatment of Alzheimer's disease. However, they are not all effective and, in many cases, we at least lack the scientific evidence necessary to really validate their therapeutic impact. Indeed, in [139], Livingston et al. performed a meta-analysis of 162 studies and concluded that only behavioral management therapies, specific types of caregiver education and possibly CST had lasting effects on neuropsychiatric symptoms, while music therapy clearly had desirable effects right after administration but lacked long-term impact.

Nevertheless, as the authors make clear in their paper, lack of evidence for other therapies does not necessarily mean that they are ineffective: the studies reviewed were mostly of poor quality and therefore cannot be used to disprove the viability of the different approaches studied anymore than they can prove it. Moreover, just like with music therapy, responses to other non-pharmacological techniques are often extremely patient-specific. This means that a given technique, even though it does not have a measurable impact on the general population of patients, may still prove surprisingly effective for a few of them. In such a case, it is not the technique itself that is at fault but rather the screening process: if one can find a suitable way to select the right patients, one may turn an apparently useless treatment into a viable clinical tool, albeit for a small fraction of the population.

For these reasons, as well as to get a better overview of how dementia affects patients and caregivers, we think it is still worth brushing through some of the most widely used approaches examined by Livingston et al., even if their effectiveness remains unproven or even, sometimes, unlikely:

- **Reminiscence therapy**: Using old items to spur reminiscence and praise patients for their recall abilities.

- **Validation therapy**: Encouraging and validating the expression of feelings.

- **Reality Orientation therapy**: Using constant reminders of time, day, place and other orientation information.

- **Standard Behavioral Management therapy**: Combining the use of multiple, standard, non-dementia-specific behavioral interventions.

- **Sensory Stimulation**: Systematic exploration of sensory stimuli to lessen the effects of sensory deprivation due to age such as visual impairments.
- **Simulated Presence**: Continuous play of audio or video recordings of autobiographical material narrated by a close person.
- **Therapeutic activities**: Puzzles, games, bicycling, exercise etc. under the supervision of a therapist.
- **Environmental Manipulation**: Addition of mirrors for self-assessment, signposts for directing attention and orientation, alteration of doors to minimize exiting behaviors etc.

This list does not intend to be exhaustive but clearly illustrates the wide variety of interventions that are used in the treatment of dementia and its consequences in terms of well-being, autonomy and behavior. The important point here is that most of these techniques have shown positive impacts in at least one study, even though it often was of rather poor quality from a methodological point of view. This calls for a better assessment of these approaches as well as for an integrated treatment method, relying on the application of a patient-specific combination of these techniques to reach higher effectiveness.

8.2.2 Cognitive Stimulation Therapy

Cognitive Stimulation Therapy (CST) [140] is an integrated procedures that combines the aspects of previously existing interventions that have been shown to be the most effective. It mainly uses Reality Orientation therapy and Reminiscence therapy mixed with multiple information processing activities with specific topics such as money or faces. It is usually divided in about 15 weekly sessions, each with a given theme and is administered to a group, usually five to ten patients. Nevertheless, it aims at being very patient-specific: after a careful assessment of participants' skills and desires, a specific role is assigned to each patient. These specific functions, even though they can change during the treatment depending on patients' wishes, help structure the group and make everyone feel useful.

The guiding principle of CST is the creation of the most suitable context for demented patients to function at their highest capacity. Therefore, it for example relies on implicit learning much more than on explicit teaching: patients are always asked for their opinions, not for answers, so as to limit the possibility for failure, which could lead to lowered self-esteem and, eventually, refusal to continue with the treatment. Also, explicit, tangible cues such as the "reality orientation board" or flash cards[1] are used to help

[1] Flash cards are big cardboard cards with just a few useful words such as the date or the therapist's name written in large, easy to read letters.

concentration and support orientation and reminiscence, which are encouraged both as signs of better functioning and as sources of pleasure. Finally, therapists strive to create a sense of consistency and continuity throughout the treatment to facilitate learning and minimize confusion.

CST has been shown to lastingly reduce disruptive behavioral symptoms as well as depression across multiple studies [139]. At least one of these works [145], with a reliable methodology and large sample group, also showed a statistically significant impact on cognition (MMS scores), on par with current drugs, and a substantial improvement in quality of life. These encouraging results call for a wider use of this technique but need to be completed with a truly large-scale, prospective study before they can be safely generalized. However the current evidence appears sufficient for us to draw extensively on the best practices defined by CST practitioners in the design of our tools.

8.2.3 Music Therapy

The rationale for using music therapy in the treatment of Alzheimer's disease is as simple as it is compelling: for a large majority of patients, musical sensitivity, in particular regarding songs discovered during their childhood, is one of the very last cognitive capabilities to disappear. In effect, this almost guarantees that music therapy will at least elicit some kind of response from even the most disabled patients, be it singing and dancing or mere focused eye movement. That in itself, although it might seem inconsequential, is in fact crucial and must not be overlooked. Indeed, as we said in Section 8.1.1, many demented patients become more or less completely apathetic after a while. Therefore, simply finding a technique that they respond to is already very valuable and the very good performance of music therapy in this respect makes it a worthwhile candidate for further investigation.

Moreover, serious studies with rigorous statistical analyses have shown that techniques such as U-Cycle Receptive Music Therapy, which we briefly described in the introduction, efficiently reduce the anxiety levels of mild to moderately incapacitated patients [7]. This in itself is a very significant result, as the U-Cyle protocol is rather easy and cheap to implement and thus constitutes a very good first step in the introduction of music therapy in everyday clinical practice. However we think one could reasonably hope to go far beyond that, as music has been seen to have much more dramatic effects on some patients, going so far as to restore seemingly lost high-level cognitive functions such as planned and coordinated complex movement for dancing or even language itself [4].

Finally, music therapy has a powerful impact on the opinions about the patients that their family and their caregivers have. It is rather common to hear visiting spouses or children state that seeing their beloved one show such a positive and elaborate response to music makes them feel as if they were in front of the person they knew before the illness took its toll on his or her capacities. In a similar fashion, music therapy positively impacts staff's general mood in institutions, as they understandably are much more motivated and happier to take care of patients who still seem lively and outgoing. This positive influence on caregivers and family in turn benefits the patients themselves as they get better care and, probably even more crucially, realize that they are better considered by those around them, which greatly impacts their self-esteem.

However, incorporating active music therapy with instruments in the treatment of dementia can be difficult. First, there is a lack of properly trained music therapists even though demand is growing thanks to influential supporters such as Oliver Sacks. Second, patients usually cannot use elaborate instruments. As a result, traditional active music therapy sessions, though in fact therapeutically effective, often end up as somewhat unappealing to patients who are too afraid to or simply cannot sing, with the therapist doing most if not all of the instrumental playing.

We think using a video game-based approach can alleviate at least some of these problems:

- By building on the success of the Wii in elderly care institutions [134] and providing data logging for easy assessment of patients' progress, we intend to convince geriatricians to consider and support the use of active music therapy.

- By providing ways for non-MT practitioners to use it in virtually any setting, including the patient's home, we hope to help establish active music therapy as a standard practice in dementia treatment and encourage institutions to go one step further and hire a real music therapist.

- By offering a virtually infinite library of customizable instruments and interfaces, we aim at helping active music therapy become more enticing and patient-specific.

8.3 Well-Being in Multiple Contexts

As explained above, since dementia usually cannot be cured we must focus on reducing its consequences. Indeed, if the various therapies mentioned in Section 8.2 sometimes do intend to have some sort of impact on the cognitive abilities of patients, hereby reducing the symptoms themselves, they are much more likely to primarily impact overall well-being. In fact, many techniques are designed with just this in mind and disregard cognitive enhancement: behavioral management, for example, only targets the behavioral manifestations of dementia, while validation therapy mostly targets self-esteem and apathy.

However well-being is far from being simply a matter of therapy. In fact, when assessing and trying to enhance well-being, one must take into account many parameters besides therapeutic processes and consider patients' lives as globally as possible. Otherwise, even well-thought, potentially very effective interventions can fail because of utterly simple matters that just have not been thought through, such as disturbing noises from outside or even simply insufficient lighting[2]. Thus, we need to perform such a global analysis to ensure that our game does not suffer from this kind of simple but critical flaws.

To this end, we first examine the most common environmental adaptations implemented in demented patients' homes and specialized institutions. We then cover the best practices in terms of support for caregivers, something which is absolutely crucial as dementia puts far more burden on them than other common conditions such as diabetes or motor disabilities. Finally, we take an in-depth look at select occupational activities and explain the rationale for their use with demented patients.

8.3.1 Adapted Environments

There are four main aspects to home adaptation for demented patients: safety, mobility, support for daily activities and behavioral management. Each one of these areas illustrates some of the issues we will have to tackle when designing our system.

Safety

Demented patients can have a distorted or even completely inappropriate perception of danger. This, added to their memory problems, makes it very important to install several safety modifications in their living spaces. First, dangerous objects or appliances must be either locked in a cupboard or require a code to be turned on. This is particularly important for cookers and ovens, which, if left on, pose serious burning and fire threats. Second, heavy objects, objects that can break, furniture with sharp corners or any other thing can physically harm a person but cannot be removed must be carefully examined and chosen as sturdy and non-threatening as possible. Third, necessary commodities must be adapted: hot water temperature must be lowered and radiators protected to prevent burning; power outlets need to be protected or locked in place; chimneys should be condemned etc.

Overall, demented patients have a tendency to manipulate objects in ways that are difficult to predict. Moreover, their motor disabilities and memory and attention problems make them prone to tumbling, dropping or

[2]Elderly patients' eyes are commonly much less sensitive to light than those of the general population [146].

breaking things. Consequently, we must make sure that the controller we use satisfies a few safety criteria:

- It must withstand shocks if dropped from a reasonable height.
- There must be no sharp corners or edges, or they must at least be covered with foam.
- Demented patients should not be able to tear it apart.

Mobility

Improving mobility at home is key to a patient's well-being, as moving around easily makes it possible to remain autonomous for a much longer time. Nevertheless, the most central concern is again safety. Falling, a very common cause of injury for elderly people, is not directly related to dementia, since balance and support issues as well as body fragility are more or less as frequent in demented patients as in the general population of the same age. However dementia-related behaviors such as wandering make mobility adaptations even more crucial. Additionally, since injuries due to falls are a leading cause of institutionalization of elderly patients [147], our objectives in terms of home stay make this issue central in our approach.

First and foremost, ground-level housing must be preferred to prevent falling. If it is not possible to have everything on one floor, stair chairs must be installed. Moreover, anything on which patients might trip, such as low furniture, power cords or carpets, must be removed or concealed. This also means that caregivers must be wary of small objects that might have been left on the ground by forgetful patients. Second, grab-bars, mechanized beds and similar assistive devices must be placed wherever necessary in order to make it easy for the patient to move around effortlessly, as being tired greatly increases the risk of falling. Finally, lighting and visibility conditions must be improved. Nightlights should be installed in hallways and bathrooms, reflective tape placed on the floor to help orientation and signal potential hazards such as low ceilings and overall lighting levels augmented to adapt to elderly patients' loss of visual acuity.

In the design of our product, these guidelines can be translated into three important requirements:

- Hardware requirements should be kept to a minimum to limit the number of cables and devices on which patients might trip.
- Playing must not be too tiring so that patients do not risk falling due to exhaustion when they stop playing and go somewhere else.
- Large shapes and bright colors must be used to compensate for patients' vision impairments.

Day-to-day Living

The most important thing to make demented patients' daily activities easier is to help them orient in time and space. For time, this means placing calendars and clocks in prominent places in each room to prevent behaviors such as going to the dinner room every 15 minutes because it may be time to eat. For space, using signalization across the house such as reflective tape markings to indicate the way to a given room and reminders of all sorts such as labels on the cupboards makes autonomous navigation much easier.

However orientation is useless for patients if they are not able to accomplish their daily tasks autonomously. Consequently, to prevent anxiety and execution problems, the arrangement of furniture and appliances must be consistent across different rooms and changed as little as possible over time. This way, demented patients have a better chance of being able to accomplish their daily tasks instinctively, whereas a new arrangement may block them in the middle of something since their executive disabilities make even small adaptations very difficult. Moreover, the tasks themselves should be made as easy and straightforward as possible, using simplified clothing, precooked food conditioned into portions that can be eaten with the hands, motor deficiency-adapted grooming tools, auto-dial phones etc. Any step that is automatized or altogether removed from a complex task is one less chance for patients to get confused.

Again, these recommendations translate into specific requirements for our design:

- The system must use strong, simple and consistent visual cues to help patients understand what they are doing.
- The system should include options to assist or even fully automatize as many tasks as possible to adapt to patients' disabilities.
- Gameplay should be consistent across all game modes to avoid confusing patients.
- Changes from version to version should be implemented very gradually to avoid forcing patients to readapt to the game.

8.3.2 Help for the Care Givers

As we have stated multiple times already, one of the main problems of dementia is that it puts a high physical and mental burden on caregivers. First, demented patients often need nearly permanent surveillance as they are always at risk of exposing themselves and others to danger, notably by wandering outside and using dangerous appliances. Second, numerous stressors come into play to aggravate the distress caused by the very time-consuming, physically exhausting routine care. No exhaustive survey exists in this regard, but several studies such as [148] and [149] point to common sources of stress; disruption of family routine, sleep deprivation, restrictions on social life, difficulty for holidays are the most commonly cited. Finally, anticipatory grief and transition to institutional care add to the anxiety and depression commonly experienced by caregivers. In the end, all those factors combine to create an actual health problem, especially for spouses: caring for their demented partner increases their mortality risk by 63% compared to non-caring spouses [150].

All in all, the onset of dementia in a family member always disrupts a household to quite a large extent, regardless of how much help the family has access to. However giving proper instruction and support to those who have to learn to care for a demented person can have a significant impact on their mental and physical health, which in turn enhances the patient's quality of life too. The first thing to do is to provide caregivers with training in behavioral management techniques, preferably in the form of psychoeducation. The exact techniques vary, but the basic point is to teach them how to change their interactions with the demented persons in order to improve communication and limit distress. Most importantly, this means gaining a better understanding of the kind of challenges that demented patients face and adapting discourse and behavior to make the best of the abilities their loved one may still possess. In [139], Livingston et al. review multiple high-quality studies that show that such an intervention can improve mood in both patients and caregivers, reduce behavioral symptoms and delay institutionalization.

Nevertheless, it remains more or less impossible for caregivers of a demented person to live a normal life. Most importantly, as explained in [149], the difficulties and stress associated with taking holidays as well as the many restrictions imposed on social life leave them longing for leisure and sleep. For these reasons, it is very important to provide day or respite care for demented patients so that their usual caregivers can take a break. As shown in [151], patients who benefit from this kind of in-home services early in their illness are, on average, kept at home longer, which positively impacts their mental health and life expectancy.

We think that providing caregivers with a music therapy tool they can easily use at home can be instrumental in improving their mood and enhancing communication and interaction with their demented relatives. However, their necessarily very close involvement in care, as described here, commands that we carefully take their concerns into account too, in addition to those of patients and physicians:

- We need to make sure that our system emphasizes the players' strengths in order to show caregivers a more enjoyable picture of their loved one, thereby reducing stress and anticipatory grief.

- The system has to be easy enough to use so that auxiliary caregivers who temporarily relieve the regular ones have no trouble with it and can ensure treatment consistency.

- We must tailor our design to encourage interaction and communication, as we hope that sharing a fun activity will help caregivers take time to closely watch their demented relatives and learn how to better interact with them.

8.3.3 Occupations for Patients

Demented patients, especially in the later stages of the illness, have a tendency to become apathetic. Their depression makes them approach any kind of new activity as either an uninteresting hassle or an impossible challenge. This partly explains why patients in institutions spend almost all of their day waiting: one would think that with so much time on their hands they would be eager to participate in various activities, but their low expectations in terms of pleasure and their fear of failing in fact cause such an apathetic behavior. Consequently, it is very hard for caregivers and institution staff to find something that demented patients can occupy themselves with, especially if they have to be autonomous. Properly trained animators however usually do manage to entertain them, but only thanks to a careful choice of adapted activities and a lot of dedication.

According to Pierrette Despres, in charge of animation, the one thing that seems to work best for the patients of Saint-Maurice hospital is cooking. Patients gather in the animation room and, following the animator's instruction, peel fruits, mix dough etc. to make a given dish, usually some kind of cake. This activity works very well with patients because it is extremely intuitive: they have been cooking for their entire life[3] and are proud to show that they can still accomplish this kind of task. Moreover, cooking comes with a reward since patients get to eat what they have cooked. For many of them, it is the only occasion to eat a little sugar as diabetes and other afflictions force them to follow a specific diet[4].

The second type of occupation we find interesting for our work is visual and tactile art: drawing, painting or sculpture activities are most of the time very enticing for demented patients if presented properly. The goal of this kind of animation is to encourage creativity and motivate patients to use their cognitive and motor skills so as to slow down their decline. This can work because patients with dementia often retain a good deal of creativity until the end and, most importantly, are usually delighted to see their creation take shape in front of their eyes. However, many occupational therapists

[3] Most demented patients are women who were born and raised in a time when gender inequalities were hardly a concern.

[4] Depending on patients' state, physicians do not always grant animation staff permission to ignore diet recommendations. Since it is unthinkable for patients not to taste what they cook, recipes must be adapted accordingly.

and animators relate that drawing the first shape or writing the first words is often very difficult because of patients' executive impairment. Therefore, in this kind of context the main role of the caregiver is to provide patients with a starting point, for example by offering to draw a first shape together with them [152]. After that, patients usually get excited by what they are doing and it is not rare to see some of them paint for more than one hour straight, which is extremely long when one considers their attention deficits.

This gives us three important hints for our design:

- The system will have to be just like cooking: extremely simple and intuitive and yet rewarding. Otherwise it will not appeal to all patients and will fail to serve its purpose of an accessible occupational tool.
- Using sounds and songs like nursery rhymes, which are profoundly hard-wired in patients' brains, will most likely yield the best results, as patients are not particularly keen on listening to new songs or trying new recipes.
- The system should give a prominent place to caregivers, as they will most likely be needed to provide a starting point and an encouraging atmosphere, no matter how much effort we put in making the game intuitive and fun.

Chapter 9

Design and Testing Protocol

After a thorough review of the context in which our target populations live and interact, we can start defining our tool itself. This chapter first lays out our objectives and formalizes the multiple constraints inferred from our assessment of the current situation regarding dementia and its treatment. Then, we explain the design process and implementation choices that resulted in our first prototype. Finally, we cover the two testing phases we conducted separately: first, incremental testing, which we used to correct and refine our design and, second, usability testing with a fixed design, required to justify an upcoming large-scale study.

9.1 Objectives and Constraints

Demented patients have very specific needs and capabilities; they cannot be considered simply as healthy subjects with uniformly diminished cognitive abilities. Indeed, although the illness at first glance appears to impact cognitive functioning as a whole, a closer analysis reveals that dementia progresses in a rather selective and often counter-intuitive manner [153]. This means that patients may retain capabilities that one would have guessed would be quickly lost while other, seemingly much lower-level abilities vanish at a surprising rate. Although it is far from being the only one, music is a very good example of this: patients who are unable to remember a list of two objects for more than five minutes are often capable of recalling and singing a whole song that they have learned a long time before. This shows that memory is a very complex function with multiple components that are affected by the illness in very different manners, making it extremely dependent on content and context.

Consequently, we need to take these specificities of dementia into account in our design process. To better specify what this implies, we first define renarcissization and discuss what makes it our primary long-term objective. Then, we consider the three main design constraints we derived from the global study of the illness we conducted in the previous chapter: low gameplay requirements for patient usability, low hardware and training requirements for caregiver usability and positive, rewarding outcomes for both.

9.1.1 Renarcissization

Although its meaning is rather intuitive for people familiar with psychology vocabulary, the term renarcissization itself is rarely used, especially in English-speaking countries. We thus rely on Dr. Péquignot's experience to define it as follows:

Renarcissization is the process of restoring patients' self-esteem by having them take part in activities that strongly highlight their skills and strengths, thereby helping them to regain confidence and control over their own abilities.

Besides reducing patients' depression levels, we think renarcissization could have a very significant impact on their and their caregivers' quality of life, ultimately reducing the tremendous economic burden that dementia imposes on society by delaying institutionalization. Indeed, as explained in Section 8.1.3, home care is better for both society and the patients themselves, and it is usually their behavioral disorders, not their overall health, that force families to institutionalize their demented elders. Our hope is that proper renarcissization could greatly reduce these behavioral issues.

Indeed, Dr. Péquignot observed that patients suffering from dementia frequently try to prove to their care givers that they can still live their life as usual, failing to realize the extent of their disabilities. This for example results in their trying to clean their house or cook in spite of their caregivers' recommendations, with the sometimes dire consequences exposed in Section 8.1.3. On the contrary, patients with higher self-esteem should logically be less likely to try to do things they cannot do anymore. Therefore, we think that if they are given the means to take part in activities that they enjoy and that make them feel better about themselves and their remaining abilities, especially in terms of memory, patients will not feel any urge to show off in front of their caregivers and become much easier to manage.

This calls for affordable and easy-to-use tools such as ours that untrained helpers such as family members could use to reduce or even prevent the onset of behavioral disorders in demented patients with minimal equipment and training costs. Through renarcissization, we expect that the blending of music therapy and video games within MINWii can (1) be instrumental in making demented patients feel better and (2) ease the time-consuming, psychologically-demanding burden of caring for them on their assistants and families.

9.1.2 Low Cognitive and Motor Requirements

In order to appeal to our users, we must make it easy for them to play in spite of their disabilities. Indeed, demented patients are rarely keen on trying something new and are unlikely to persist with a technological device if they cannot make use of it right away. This means that the skill level necessary to have fun on first contact with the system must be very low with respect to their motor and cognitive capacities. In order to be able to define these specifications clearly, we choose to restrict our target population to patients with mild to moderately severe impairment, i.e. with an MMS score between 10 and 25, and potentially severe but not profound motor, auditory and visual impairments[1].

Low Sensory and Motor Requirements

Conditions such as arthritis and lack of body strength prevent elderly patients from making large or fast movements. Thus, we must make sure that our gameplay does not require this kind of interaction. Also, for the same reasons, patients get tired quite fast, which means that we must make the game playable in a relaxing, sitting posture and allow for frequent pauses if necessary.

More importantly, with the damage done to their brains, demented patients have trouble coordinating multiple joints to execute a complex movement. Consequently, the number of joints involved is a key decision variable in choosing the mode of interaction: no more than one should have to work to execute the movements defining the core mechanics of the game.

Additionally, as we explained in Section 8.3.1, the eyes of elderly persons are often far less sensitive to light and their vision less precise than for healthy subjects. Therefore, the game must rely on large, brightly colored visual elements to make things comfortable for patients with moderate visual impairments.

Low Cognitive Burden

Whereas accessibility for persons with visual, auditory or motor impairments has always been an active research topic, computer accessibility for cognitively impaired individuals is a rather new concern. Indeed, since around 1995, basic manipulation of computers and web-browsing have gradually become almost mandatory in many aspects of daily life. Hence the need to (1) design computer interfaces adapted for cognitively impaired persons and (2) learn how to choose, organize and format content accordingly. It is interesting to note that the issue is the subject of intense debate in the

[1]Severe but not profound impairment means that the function is strongly diminished but remains usable in the right context, i.e. patients must at least be able to see large, solid shapes, hear very loud sounds and move one wrist.

research community, with leading experts advocating more or less opposite approaches, for example regarding the use of animations [154].

This tells us that it is most likely best to keep text content out of the way as much as possible, as there is as of today no sure-fire way of making it understandable for patients. Moreover, menus and choices, text-based or not, should be avoided wherever possible, with all the gameplay options, such as gaming mode, difficulty level or pointer sensitivity, chosen by the caregiver before play. Otherwise, given their executive disabilities, patients might get stuck when asked to make even the smallest decision. This phenomenon is strongly exemplified in [63], where experimenters relate the surprising difficulties patients had with the "Touch anywhere to begin" screen: without an actual suggestion, demented users were stopped by the need to elect a place to press with their fingers while they were perfectly able to click the clearly defined buttons that appear in other parts of the interface.

Furthermore, the gameplay must be simple enough for patients to grasp it instantly. There must be only very little conscious learning to do, as memory-impaired patients would more or less have to be retaught everything every time they play. This, in particular, means that no complex actions or button combinations should be required at any time. In fact, the gameplay would best use only one kind of action, so that patients would not have to learn any abstract, arbitrary mapping of buttons, as pressing any of them would have the exact same effect.

Finally, we must ensure that our game uses only very straightforward visual cues in order to adapt to the diminished attentional capabilities of demented patients. More specifically, there should be one and only one clearly signaled area of interest on screen at all times. Additionally, the graphic design should rely on large, easily differentiable shapes such as squares and circles, and use soothing colors, as a visually appealing interface is actually more usable [155]. Nevertheless, we believe that the extra visual elements referred to as *eye candy*, which give a game a more beautiful appearance but carry little or no meaning, should be kept to a minimum to avoid distracting patients.

9.1.3 Positive Feedback

To reach our goals, an obvious first step is to make the game playable by any individual of our target population. That is the point of the constraints in terms of motor and cognitive requirements. However, to achieve efficient renarcissization, one must go considerably further and make sure that the game actually sends as much positive feedback to players as possible, regardless of their performance.

First, like anyone else, demented patients take pleasure and pride in succeeding in something challenging, but are greatly put off by failure, as it yet again reminds them that they have become unable to do some very basic things that were no issue at all when they were younger. Thus, the game has to downplay the importance of their impairments by heavily assisting whatever action might prove too difficult. Conversely, the gameplay must greatly emphasize their strengths and only use mechanisms that rely on the abilities best conserved in dementia.

Second, while traditional video games rely on scoring to motivate players, our context prohibits the use of this lever. Indeed, while skilled patients would probably be enthusiastic about such a feature, we cannot afford to take the risk of deterring patients unsatisfied with their performance by letting them compare it to that of other players. However, there is a solution to this problem: we may include a scoring system, but it must reward effort only and put emphasis on progress. It would thus be much more similar to the experience point system of RPG games than to the performance-oriented scoring of games like *Guitar Hero*.

Nevertheless, despite the feasibility of such a system, we think that our best bet to get this kind of positive feedback is to rely on caregivers. Of course, the music in itself acts as a reward but, according to our experience with demented patients, nothing works better on them than praise from a fellow human. Once again, this highlights the need to include caregivers not only in the design process but also in the gameplay itself, in order to make sure that they too have fun and are available to give patients the encouragements they need.

9.1.4 Versatile Setup

Renarcissization is not a one-shot process. In order to enhance and then keep patients' self-esteem high, one needs to provide empowering activities on a daily basis. Of course, we do not expect patients to play our game every single day. Many other kinds of activities are available and common sense would recommend a varied occupation schedule, engaging patients' abilities in diverse contexts to maximize transferability to day-to-day living tasks. However, in order to have a lasting impact on our users, we must make it possible for them to play the game often and in many different contexts including, but not limited to:

- Home, for use with their family, assistants or visiting nurses.
- Day-care institutions, for therapeutic use in group activities under the supervision of a psychologist.
- Hospitals, for therapeutic or occupational use, in groups or solo, depending on the context and goals.
- Specialized institutions, for therapeutic or occupational use but also to foster interaction with visitors and other patients, both in rooms and in communal spaces.

Our use of cheap, generic hardware and free software is very well adapted to this need for flexibility. Indeed, it gives healthcare practitioners the opportunity to set up a system for a very small cost, relying on things they likely already have at hand such as a computer and a TV. However, we still need to make sure that (1) the game is playable on screens of various sizes and qualities and (2) that the interface and configuration menus are usable by people with possibly only basic computer knowledge and, almost systematically, very little time to learn how to use a new system.

Furthermore, versatility also imposes constraints on the research process itself. In order for us to design a tool adapted to all these environments, we must gather data regarding its performance in each of them, with as many hardware and software configurations as possible. Consequently, we need to plan early on for the diffusion of the application among the community, as our limited resources clearly make it impossible for us to conduct all these tests on our own.

9.2 First Design

After a careful review of the pathology and its consequences on the life and overall well-being of patients, we started working on a first design with Dr. Péquignot. In this section we explain and justify the design choices we made, many of which implied important trade-offs. We do this by successively analyzing five of the most prominent features of MINWii: simple components, pointing-based gameplay, failure-free use, familiar sounds and caregiver involvement.

9.2.1 Simple Components

As stated before, we have chosen to rely exclusively on off-the-shelf components in order to build a system that could be installed pretty much anywhere for less than $1000, which is roughly the average price of a one-day hospital stay. The only necessary equipment is: a standard computer ($500), a computer-enabled TV screen ($400), a wireless infra-red Sensor Bar ($20) to be placed below the screen and at least one Wiimote ($40). We did use commercial sound synthesis PC software for prototyping, but the new version of MINWii, soon to be used in a large scale test, relies exclusively on free software (Pygame [156], Fluidsynth [121] etc.) released under the GNU Public License[2].

All the interactions can be logged on the hard disks of the computers for subsequent analysis. Nevertheless, even though it is not required, we suggest using a personal USB thumb drive ($15) for each patient, containing his or her preferred configuration and songs as well as logs of previous sessions, as is

[2] See www.minwii.org.

done at InGame Lab [44]. This gives a very simple way for physicians to check on their patients' evolution and greatly limits the risk of inadvertently mixing up data from different persons, as sometimes happens with centralized data management systems.

Off-the-shelf components like the Wiimote have another interesting, less obvious but probably even more relevant characteristic: they usually have a simple, pleasant aesthetic design. For demented patients who are typically over 80 years old, this is of importance since any apparent complexity, such as lots of wires or strange-looking machines, may trigger their constant fear of failing and breaking objects. Dr. Péquignot's experience with personal hygiene robots [157] is a good example of this phenomenon: it showed that even carefully designed, very easy to use devices can be of little practical interest with some patients because of the adverse reaction they elicit due to their apparent complexity. Thus, in part because of issues of this kind, MINWii only uses two pieces of nowadays familiar equipment (laptop and TV) and two remote-like devices (Wiimotes and Sensor Bar). It is thus much less likely to be rejected than other, usually aesthetically unpleasant medical appliances, even if causes a certain amount of anxiety in some patients on first contact.

9.2.2 Pointing-Based Interaction

The gameplay we chose exclusively relies on the infra-red pointing mechanism provided by the Wiimote. This offers a great advantage over the traditional designs of commercial Wii games, which usually use more complex interaction schemes that fuse information collected from accelerometers, gyroscopes and IR camera: here, only wrist movements within most patients' zone of comfort in terms of amplitude are required. We chose this approach in order to accommodate for the difficulties that demented patients have with complex movements involving the coordination of multiple joints as well as to enable play in a relaxed, sitting position (see Section 9.1.2). Furthermore, MINWii heavily filters Wiimote inputs and cursor movements so that the pointer behaves smoothly enough for patients to feel comfortable. This slightly hinders responsiveness but is nevertheless unlikely to affect patients' experience as they tend to play with only very slow movements anyway.

Regarding cognitive issues, pointing is very intuitive and thus has a low footprint: as we made sure to use only one type of action, i.e. activating what the user is pointing at by pressing the trigger, the player does not need to learn a new convention such as "this button activates this" or "this arrow moves that". This is obviously crucial for patients who often cannot remember a list of just two or three items for more than a few minutes. Furthermore, we designed an extremely simple, entirely image-based graphical interface, at least for the part of the game where patients are expected to act autonomously (see Figure 9.1). We were very careful to adapt the

Figure 9.1: Instrument choice screen.

look-and-feel of the application to our population's reduced attention and focus abilities, often complemented with some degree of visual impairment. Everything on the screen is very large and highly contrasted to be easy to comprehend and we deliberately refrained from using fancy graphics and animations, even though the visual result is consequently considered somewhat unappealing by some healthy subjects.

More to the point, we also tried to accommodate for the great decision-making difficulties that demented patients usually have. The buttons on the Wiimote all do exactly the same thing and there is always one and only one active area at a time on the screen, highlighted as clearly as possible. This way, with only one method of interaction and only one object to interact with, the user never has a choice to make once the game has started and is much less at risk of feeling lost. Interestingly, this feature is at the opposite of what is usually considered as a key gameplay asset in traditional video games: while developers usually try to allow players to reach their goals using many different strategies, since healthy users will usually praise games that give them the highest freedom of action, the challenge here is to shrink the choice space while keeping the fun factor as high as possible.

Finally, to make the system look easy to use [155], we chose light pastel colors to get a nice soothing look, since this is the kind of tone that patients seem to appreciate the most. Also, all the configuration settings (game difficulty, Wiimote sensitivity, pointing mode,...) can be made by the caregiver with the keyboard or his or her own Wiimote, with no graphical output displayed to the patient. Indeed, we observed that visual indications related to such abstract notions often confuse demented patients and might induce anxiety by making the system look too complicated, just like visibly complex devices and numerous wires do.

9.2.3 Failure-Free Gameplay

Demented patients often exhibit a systematically defensive attitude regarding anything unfamiliar. They are always afraid to fail or break something when confronted with a new task. They may also give up very easily if they do not succeed right away, even when receiving strong encouragements from their caregivers. For such reasons, we designed a gameplay where failure is either impossible or very unlikely due to the simplicity of the task at hand. Moreover, if it does happen, its importance is systematically toned down.

First, no click will result in a dissonant sound since only notes belonging to the same scale and therefore guaranteed to sound well together can be played during the game. Thus, a player might fail to produce the sound he or she was aiming for but the outcome should still be pleasurable. Second, given how difficult it is for demented patients to use almost any electronic device autonomously [63], we prefer to see our system as a tool to foster interaction between patients and caregivers. Consequently, MINWii does not present judgments of any kind (scoring, game over, etc.) to the patient and relies on the supervisor to both give praise and help through failure.

The first prototype offered two different gameplays, "Improvisation" and "Song" which, although they were thought out with the help of an experienced physician, still suffered from many flaws mostly due to our underestimating patients' difficulties. They consequently evolved greatly throughout the incremental design phase and are no longer part of the game as is. However, analyzing them below gives us an opportunity to describe some of the core characteristics of the game that remain unchanged. Moreover, since we ultimately want to infer guidelines about how to drive such a design process, we must describe our starting point:

Improvisation Mode

Here, patients are invited to improvise using a scale of their choice[3] by pointing at a virtual keyboard of 8 or 11 colored keys displayed on the screen, depending on their level, determined beforehand by the care giver. A large white dot shows where they are aiming at and highly contrasts with the keys in the background, which all have their unique pastel color and display the name of their note in French. The closer to the top of the screen one clicks, the higher the volume is (see Figure 9.2). Though it is hard to

[3] C major by default.

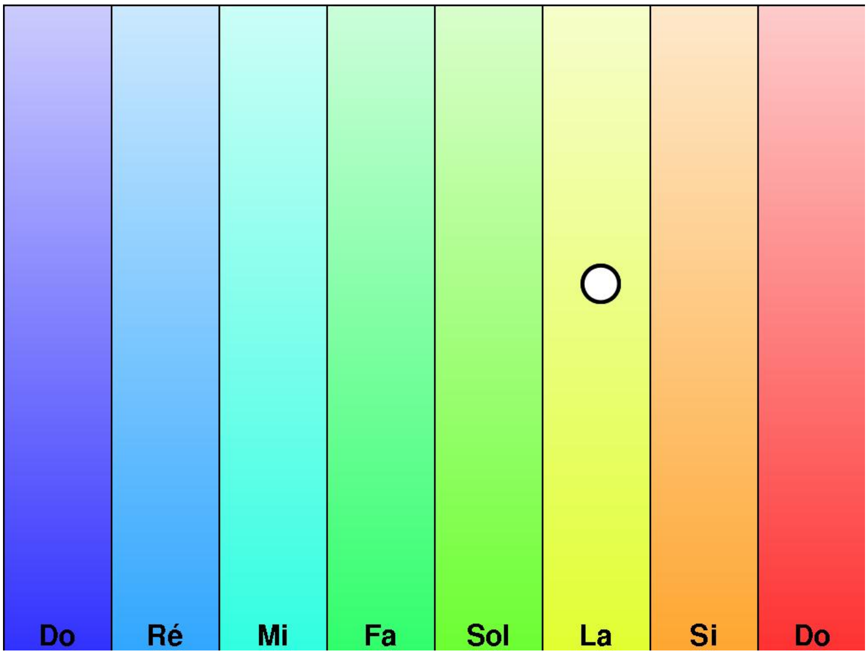

Figure 9.2: Improvisation screen.

play fast, rather elaborate melodies can be played quite expressively at a slow tempo. However the temptation to speed up can be great, so we added a *glissando* option that can be switched on or off by the caregiver; this allows for more "experimental" improvisations, but makes it much more difficult to play expressively.

Song Mode

The very first version of the Song Mode was exceedingly simple: we took the improvisation screen, highlighted a target note and made all the other notes dark and pale so that the area to click really stood out. Also, in order to have a failure-free gameplay, we kept the possibility to play the dark notes so that players would not feel stuck and get frustrated when they clicked somewhere and no sound came out. However we made the sound of these dark notes much softer so that it remained clear that playing them was not necessary, in essence giving them the function of possible ornaments for experienced players.

We started with just a few simple songs that we hoped patients would remember: several nursery rhymes and a few tunes that were popular when they were young and went to balls. The aim here was to offer some songs that were easy to play and remember and some others that would be more difficult but likely to be tied to happy memories of partying as youngsters.

9.2.4 Familiar Sounds

Music therapists always pay very close attention to the sounds they use because they can make or break a treatment, depending on how they relate to a patient's personal tastes and sonorous history. In this study, as none of the designers were trained in music therapy, we probably did not emphasize the sonorous dimension *per se* anywhere as much as a true music therapist would have. However our purposes are slightly different than those of traditional music therapy as, with the use of a screen and the introduction of some game-like mechanics, it is not really musical discourse and performance that interest us here. Consequently, we did not take expressiveness too much into account when we chose the virtual instruments included in the game. We simply made sure that they were of sufficient quality, which for the most part simply meant that they did sound like the real instrument they were recorded from.

What we did pay attention to, however, was how the instruments related to each other and to our patients' general sonorous history. First, we used only analog instruments with a rather soft tone, so as to avoid extreme frequencies that patients might not be able to hear or even could cause pain due to auditory impairments such as tinnitus. Despite these restrictions, we nevertheless tried to create a palette with a wide variety of timbres in order to offer appealing sounds to as many patients as possible regardless of their musical preferences.

More importantly, as we did for the choice of songs, we picked instruments that we believed would mean something to our patients given their overall cultural background. This is a very population-specific step and, had we meant to try our system with people from India or South America, we would most likely have chosen our instruments and songs very differently. Here, we targeted French patients who, given their age, share three main sources of musical experiences: classical Western music, represented by the violin, piano, flute, cello and tuba; church music, represented by the organ and the bells; "musette" balls, which were very popular during the 40's and 50's and are here represented by the accordion and the guitar.

9.2.5 Caregiver Involvement

Our very first idea was to design a game that demented patients would play fully autonomously at their own initiative, which is the traditional approach in most games, even in those that are deemed *serious*. However, through review of the literature [63] and brainstorming sessions with Dr. Péquignot, it quickly became clear that this would mean creating something either so simple that it could barely be called a game, especially if we were to use only off-the-shelf components, or something that would be too complicated for all but the least impaired patients, a population which is already the target of a game rather similar to ours, SGCogR, currently under development at Tekneo [158].

Consequently, we decided to include caregivers in the gameplay from the beginning, which allowed us to make the game far richer and more complex than it would otherwise have been, in particular in terms of flexibility and adaptability of the gameplay to different patients. This primarily affects the design of the starting menu, which, instead of using only images if it had been targeted at patients themselves, is very similar to that of a regular computer application, except for two things:

- We wrote everything in large fonts and avoided technical-sounding vocabulary. This way patients, even though they are unable to navigate through the menus since all the controls are in the hands of the caregiver, can still read what is on screen without being either frustrated because they cannot make out the letters or scared because the system seems too complicated. This is very important since patients tend to read out loud whatever is written in front of them more or less automatically. With a proper menu layout, we avoid the issue of frustration due to failure at deciphering unreadable words and even give caregivers a good occasion to praise patients' ability to read.

- MINWii's file browser fetches a well-formatted title from song files without loading them, similarly to what media players do with MP3 tags. This way, patients can easily read "Les feuilles mortes (Yves Montand)" instead of "feuillesMortes.xml", which they may have trouble understanding and thus might see as a frightening sign of complexity. Moreover, just like everywhere else, all unnecessary information has been removed so that nothing can distract patients from the song names (see Figure 9.3).

Besides the configuration and menus, we rely on caregivers for one more crucial thing: feedback for patients. Indeed, as we said in Section 9.2.3, there is no scoring system in the game since the idea of failure, and therefore success, makes very little sense in MINWii. In any case, if failure remains possible, for example in Song Mode, we certainly do not want to underline it with any reward mechanism. Therefore, it is up to the caregiver to praise the patients for their performance, something they are much more apt at doing than any automatic congratulation mechanism such as that of *Guitar Hero*, which would most likely disturb patients' concentration anyway.

9.3 Incremental Testing

The first and longest testing phase, as mentioned in the beginning of this part, was conducted at Saint-Maurice Hospital under the supervision of Dr.

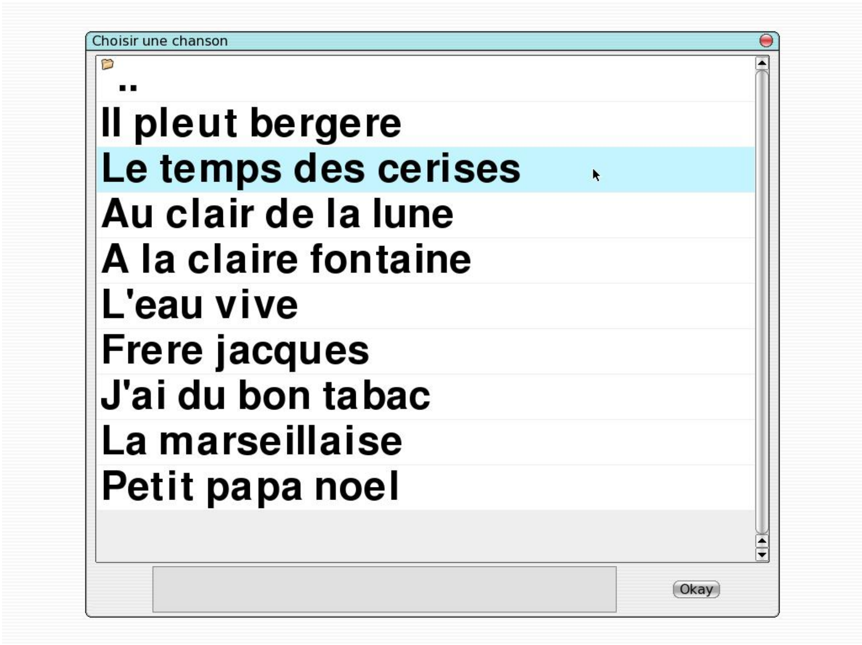

Figure 9.3: MINWii's custom file browser.

Renaud Péquignot, with invaluable help and feedback from Pierrette Despres, in charge of animation. Here, we describe the target population for this phase and explain how we implemented patient-centric incremental design with testing in a real clinical setting, which is one of the cornerstones of our framework. Then, we focus on three major improvements that resulted from this approach: better Wiimote handling, Challenge Mode and finally Reminiscence Mode.

9.3.1 Population and Protocol

To get a good sample of our target population (see Section 9.1.2), we tested our system in the Geriatrics Unit of Hospital Saint-Maurice, where patients usually stay for up to two months, depending on their condition and on the follow-up care available. They are usually not admitted because of their dementia or other chronic problems but for temporary issues such as recovery from surgery. In the best-case scenario, they go back to their home after about a month of treatment. However many patients end up in a specialized institution after their stay: even though they often can be cured of the conditions that brought them to Saint-Maurice, the process still takes too big a toll on them to allow them to go back home safely afterwards.

For each session, we selected several patients with suspicion of Alzheimer's disease, a Mini Mental State score [142] between 10 and 25 (out of 30) and no profound deafness, blindness or motor disabilities. From November 2009 to March 2010, once a week, those who were available were encouraged to come to the animation room and "play music with the remotes", for a total of 18 sessions. As participation was voluntary and therefore greatly depended on both the patient's mood on that day and the overall relationship he or she had with the caregivers who were proposing the activity, some of our test subjects played only once while others joined almost every week of their stay. However this variability was not an issue since our goal was simply to improve the system using anecdotal evidence before undertaking controlled studies[4].

We usually ended up with a group of 3 or 4 patients whom we would sit together in a semi-circle in front of the projection screen in the animation room, which made it clear to them that this was a group activity. They would each be given a Wiimote and then would take turns playing the song of their choice, with staff members sitting next to them and giving as much help as needed. After each session, we would have a debriefing meeting with the staff members involved that day to discuss flaws that needed to be corrected and potential improvements regarding not only the system itself but also the organization and method used to conduct the sessions, such as the timeline, vocabulary used, amount of help provided etc.

9.3.2 Wiimote Handling

Demented patients, due to their frequently rather old age, usually have many moderate issues besides their cognitive impairment, such as low movement amplitude. We realized during the very first session that because of conditions such as arthritis, many would not be able to bend their wrist downward sufficiently to point at the screen with the Wiimotes: test subjects were always aiming rather far above the projection area, so that supervisors had to take their hand and guide them, consequently more or less playing in their stead. Our first idea to work around this was to place the sensor bar high above the screen too, so that the Wiimote would be able to pick its signal up when held almost upwards. However this solution, besides forcing us into crafting a custom sensor bar holder, was rather unsatisfactory due to the large discrepancy it induced between where the pointer was on screen and where the Wiimote was actually pointing.

Dr. Péquignot then jokingly suggested that we use a pistol instead of the Wiimote to make things easier for patients. However, when he made that joke, he was not aware that an accessory such as the Wii Pistol (see Figure 3.2) actually existed. This hollow plastic gun, in which the Wiimote can be encased, makes it very easy to hold the Wiimote and enables playing without having to bend the wrist. After a short discussion regarding the way

[4] We were able to conduct this testing without having patients sign anything, since we did not need to collect any personal information about their participation. However, as a consequence, no precise records of attendance exist.

it would affect patients, we decided to give it a try the following week, even though we did fear that it would shift the focus of the game from playing music to shooting and, much worse, could trigger undesirable reminiscence of patients' potentially violent past.

Indeed, besides making things easier from a motor point of view, the pistol shape, for the same reasons that it may encourage sad reminiscence or even aggressive behaviors, obviously has a strong affordance[5] for the task at hand. In fact, guns and their depictions are so ubiquitous in our society that even the most diminished patients were able to recognize and understand the purpose of the controller we gave them, which was an invaluable asset for us.

In the end, these observations clearly highlight the advantages of using off-the-shelf components: instead of having to build a custom contraption, a quick run to the store made it possible to try our new idea right away without any significant effort. Furthermore, while mounting the bar above the screen would have at best solved only the issue of wrist bending, thanks to the affordance of the Wii Pistol we significantly improved the gameplay in multiple areas at almost no cost.

9.3.3 Challenge Mode

Although patients were almost invariably enthusiastic about playing songs of their choice, the first version of Song Mode was clearly too difficult for them. They were often unable to hit the highlighted bar even after several attempts, mostly because their grip and posture were not solid enough to keep the pointer steady and in place when pressing the trigger. Thus, they did not really feel empowered when they played, as they required extensive help from the caregivers supervising the session. Although they still seemed to take great pleasure in the activity despite the fact that their helpers did most of the playing, such a gameplay was unlikely to induce renarcissization and had to be changed to meet our objectives.

In the new version, which we renamed Challenge Mode, the patient still clicks the keys that highlight successively according to the song chosen. However, there are a few crucial differences that make it much easier and more enjoyable. First, caregivers can control whether clicking the wrong note produces a sound or not. This is very important since we saw that even though their volume was much lower, wrong notes still distracted and confused patients and were not at all used as ornaments like we thought they could be. Second, caregivers can also decide to allow partial hits or not. By *partial hits* we mean the fact that the patient clicks outside of the target note but then manages to bring the pointer in the right area without depressing the

[5] In this work, we use the definition of affordance which prevails in the Human-Computer Interface community: the capacity of an object to suggest its own use within a given context.

trigger. Allowing partial hits makes it much easier to play but can be somewhat confusing since it makes it less clear which areas are active and which are not. Third, and most importantly, we made the highlighted note triple in size and cover the two adjacent ones. Aiming is consequently much easier, especially when playing consecutive degrees, which make up for most of the intervals used in popular songs.

Although aiming and clicking at a reasonable pace without too many errors still seemed to be a big challenge in spite of our gameplay modifications, we started hearing patients say things like "It's hard, we have to remember the lyrics" or "I remembered only because you helped me". In fact, they very rarely commented on the difficulty of the task itself but, on the contrary, often made remarks about the difficulty of remembering melodies and lyrics. This was a big surprise since, probably thanks to our choosing mostly nursery rhymes that are engraved in the brain of virtually anyone raised in France, they were actually able to recall the songs quite well.

These remarks lead us to add lyrics to the virtual keyboard, coming back on the decision we had made not to use any text in the parts of the interface intended for patients. Although displaying them karaoke-style, i.e. sentence by sentence at the bottom of the screen, is useful to understand the meaning of the words and forecast what is coming next, we thought it would be too taxing for the limited attentional abilities of our test subjects, who would most likely experience difficulties to go back and forth between the highlighted note and the lyrics. We consequently chose to display each syllable in large letters right in the center of the corresponding highlighted note. This approach prevented patients from having to switch their focus between different areas of the screen and was considered more beneficial than the karaoke layout, although it failed to provide the same contextual information.

9.3.4 Reminiscence Mode

Once we added the lyrics to the virtual keyboard, patients started singing along much more enthusiastically. Moreover, the various gameplay tweaks we had introduced, in particular highlighted note inflation, enabled us to let them play much more autonomously, giving much lighter and less frequent help than before. Nevertheless, it remained impossible for them to play with the proper rhythm, or even close to it: pointing and clicking, given their diminished skills, was doable but far too slow to let them play the songs as intended.

However, as we said earlier in this section, patients did not seem at all concerned by the fact that they needed so much help to perform the songs more properly, even when the end result remained largely unsatisfactory in terms of musicality in spite of caregivers' heavy intervention. This shows that they either were not really aware of how much assistance they were given

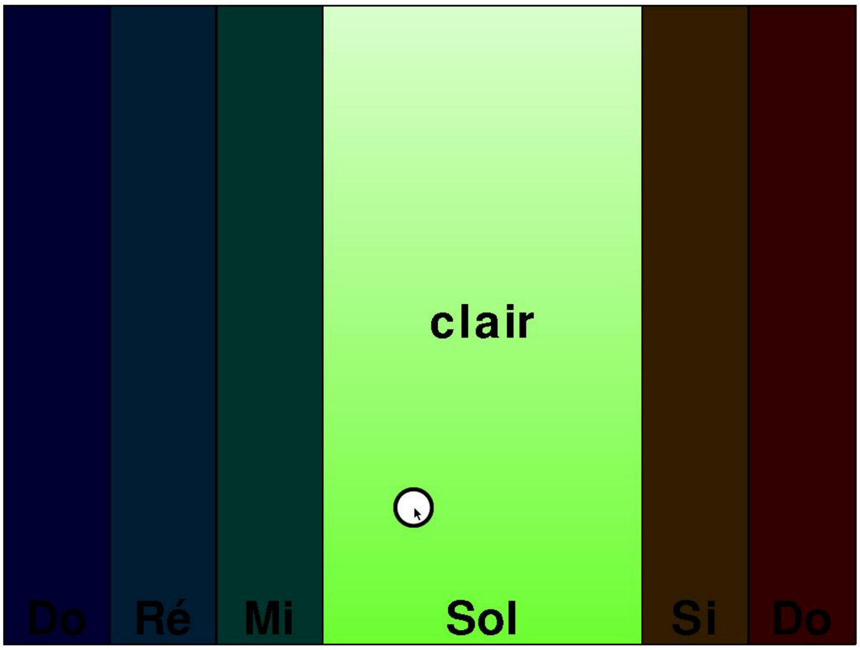

Figure 9.4: *Au clair de la lune* in Reminiscence Mode.

or simply did not care about properly pointing and clicking. In any case, they did not seem to mind that the caregiver was actually doing almost all of the Wiimote handling for them; they appeared to be incomparably more focused on their ability to remember the melodies and lyrics to the songs. This convinced us to try to explore a new direction, even if it meant loosening our interpretation of the “easy to use, hard to master” rule of game design.

To focus the gameplay on reminiscence, we lowered the game’s difficulty to a level well below what we had intended in the beginning. In Reminiscence Mode (see Figure 9.4), instead of having to click in the right place to play, patients can simply hover over the highlighted notes with the trigger pressed in, and the system makes sure that the melody is played with the proper rhythm. One can thus play without even looking at the screen by simply pushing the trigger and shaking the Wiimote from left to right, something that one of our test subjects, even though severely disabled, was thrilled to discover with some practice. Seeing the success of this type of gameplay (see Chapter 10), we went even further and added a mode where pressing the trigger is not even required. This proved useful for some patients but did remove enough sense of control for others to complain, which led us to include both options in the final version, in the aim of appealing to as many patients as possible.

9.4 Usability Testing

Once we had obtained a sufficiently refined design, we started a pilot study with a fixed version of the software and systematic trials. Our goal was to methodically demonstrate MINWii's adequacy with the needs of demented patients and its easy integration in existing protocols by trying it out in a different setting with a different approach and, most importantly, with new session managers who were not involved in the design process. This phase was conducted under the supervision of Pr. Anne-Sophie Rigaud at the LUSAGE, a research unit of Broca Hospital in Paris. Two Broca psychologists, Sandra Boefsplug and Mélodie Boulay, directed the testing sessions twice a week.

Here, we first describe our smaller but this time fixed test population. Then, we explain the organization of the sessions, which was quite different from the previous study. Finally, we list the measurements this systematic approach allowed us to perform and explain their relevance.

9.4.1 Population and Protocol

We recruited seven patients hospitalized in a long term care unit at La Collégiale Hospital in Paris for this study. They all suffered from Alzheimer's disease according to -ADRDA[6] diagnosis criteria [159]. MMS score ranged from 12/30 to 22/30 with a mean score of 16.71. The sample sample was composed of 4 women and 3 men aged from 77 to 95 years, with a mean age of 88.5. Contrarily to those at Saint-Maurice, the test subjects involved here were all long-term patients, even though some of them still expected to go back to their home in spite of the physicians' opinion.

The testing sessions, which this time were individual to eliminate potential biases due to the influence of other players, took place once a week, for approximately 10 to 20 minutes per patient, in the living room of the LUSAGE User Lab at La Collégiale Hospital [160]. One psychologist sat next to the patient playing to give instructions and help if needed, while the other carried out observations. An engineer was also present to setup and launch the prototype and observe the sessions.

To get reliable measurements, we decided to try only the Challenge Mode without partial hits (see Section 9.3.3, as the Reminiscence Mode was too assistive for us to properly qualify errors. We proceeded as follows:

- First, we arranged one training session to let patients get familiar with the interface. This comprised four tasks designed to go from the sim-

[6]This test is specific to Alzheimer's disease and is thus very different from the MMS, which measures cognitive impairment regardless of its causes. Such a diagnosis is not very relevant for this thesis, as MINWii targets all demented elderly patients, including but not limited to those with Alzheimer's disease. However, precisely characterizing our test subjects' conditions was important for the LUSAGE's own research.

plest to the most complex action: 1) four shots at a single colored strip: we asked the patient to aim at the strip and press the trigger to produce a sound; 2) four shots at two colored strips: the patient had to alternatively aim at each strip and press the button to produce two different sounds; 3) four shots at a single, moving colored strip: each time the patient activated the note, the strip disappeared and reappeared elsewhere; 4) we finished the familiarization sessions with one try at the test song, *Au clair de la lune*.

- We followed the first, familiarization session with three sessions where patients played the test song twice in a row. There was no obvious sign that the song looped back to its beginning since MINWii leaves the task of stopping sessions entirely in the hands of the caregiver. Nevertheless, patients did understand that it was the end of the song by following the melody or, more frequently, by reading the lyrics. If they did not play right through into the new iteration, we took the opportunity to pause for a minute, give them praise and encourage them to share their impressions and opinions.

- We concluded with a session where the patient was left alone in the room to see if an autonomous use of the interface was possible. The room configuration still allowed for exterior observation and even interventions of the psychologist if needed. We also took advantage of this last session to have patients try out the Reminiscence Mode, with a song of their choice especially imported into the system if they wanted.

All sessions were video-recorded in order to carry out a systematic analysis of patients' utterances and a precise, a posteriori study of how they used the system.

9.4.2 Measurements

Using a fixed protocol with a fixed population allowed us to make reliable measurements to assess the adequacy of MINWii. Moreover, since we had a very small sample of patients, systematic measurements also enabled us to make quantified comparisons between them. This produced interesting albeit anecdotal evidence of the influence of various parameters such as MMS and motor disabilities.

The parameters we measured were:

1. **Efficacy indicators**: number of errors (clicks outside of the highlighted note) during each task.

2. **Efficiency indicators**: time to complete each task and number of interventions of the moderator.

3. **Semi-qualitative measurements**: satisfaction questionnaire with a five-point Likert scale and analysis of verbalizations and behavior of the patient during the sessions.

The satisfaction scale included seven questions with responses ranging from *not satisfied* (=0 points) to *very satisfied* (=4 points), giving a maximum possible score of 28. We administered the questionnaire twice, once after the familiarization session and the second time after the fourth session, as autonomous play made the fifth unsuitable for the satisfaction questionnaire.

For some measurements, we took advantage of MINWii's extensive logging capabilities to automatically record part of the data such as the number of errors and the time taken to complete each task. If needed, sessions could also be replayed in their entirety to observe specific processes and try to categorize the different types of errors patients made. Nevertheless, the analysis of behavior, verbalizations, manipulation of the Wiimote and number of verbal and physical interventions of caregivers was conducted a posteriori with the videos.

Chapter 10

Results

The two test phases yielded many interesting results, both qualitative and quantitative. What we have seen so far already enables us to conclude on MINWii's validity as an occupational tool from the standpoint of both patients and caregivers. Moreover, there are more than enough encouraging hints of MINWii's therapeutic potential to justify a large-scale randomized controlled study to truly assess its impact from a this point of view.

In this chapter, we review these results, organized in three categories. First, we cover usability issues. Then, we analyze MINWii's ability to motivate patients and generate fun and pleasure, two aspects that are at the core of any successful game, serious or not. Finally, we discuss the ways in which MINWii both nurtures and relies on human contact, justifying our decision to use group sessions and to closely involve caregivers.

10.1 Usability

In Section 1.2, we explained how crucial good patient and caregiver usability was for a healthcare game and thus constituted one of the three key points of our framework. Here, we discuss how MINWii fulfills and even exceeds the requirements laid out in this regard in Section 1.2, as shown for example by the good satisfaction scores reported by patients (see Figure 10.4). First, we cover patients' reaction to the pointing mechanism and overall motor aspects of the interaction. Second, we look at how the system integrates into a clinical environment. In particular, we examine how it meets the expectations of experienced caregivers and how it fits in their daily routine. Last, we consider MINWii's usability in terms of cognitive burden which, in our opinion, is best reflected in the amount of help patients require and in their overall level of autonomy.

10.1.1 Pointing

First, in the usability study, every patient succeeded in holding and pointing the Wiimote pistol properly from the first training session on. This observation is supported by the data we collected through the Wiimotes, which shows that during the familiarization session all but Subject B completed the three tasks relatively fast. Most likely due in large part to the high range of cognitive impairment in our sample population ($12 \leq MMS \leq 22$), there were clear differences in the amount of time patients needed to understand and start controlling the interaction mechanism. However, the fact that all but one of them were successful at basic pointing exercises shows that this interaction model is very well adapted for use with most patients, even those who are significantly diminished ($10 \leq MMS \leq 15$).

We also observed that physical disabilities due to age such as degenerative osteoarthritis, after-effects of hemiplegia or small tremors did not make proper use of the Wiimote Pistol impossible. The controller was judged slightly too heavy by most patients, but most of them did not seem to be actually bothered. A lighter controller would definitely reduce fatigue but we have seen that most patients are comfortable enough to play for at least 10 minutes in a row without feeling any pain. Consequently, we think that the other advantages that the Wiimote offers in terms of price and availability, which would be lost with a custom controller, are sufficient to justify our keeping it in the final design despite its relatively high weight.

However, close monitoring by a caregiver again proved crucial as bad positions and postures had to be corrected for some patients. The posture that seemed to be best adapted, with the arm holding the pistol near the body and the elbow against the hip, was not spontaneously adopted by all. Some extended their arm forward (Subjects D and E) and quickly felt tired, whereas they were able to play for extended periods of time once caregivers corrected their position. Others had a tendency to aim as with a real gun with the cannon in the line of sight (Subjects E and F) which was quite a straining posture for their neck, shoulder and arm. Moreover, it was also misleading since, when we implemented our pointing assistance algorithms, we gave up true 1:1 correspondence between pistol and pointer to make the movement of the cursor smoother. This resulted in a small but perceptible difference between its position and the actual place the cannon of the pistol was pointing at. Having patients play in an armchair or with a tablet to support their elbow would most likely solve these problems as it would (1) suggest the proper position, (2) hide the discrepancy between pistol and cursor, since it is small enough to be noticeable only by placing one's eye directly in the cannon's line of sight and (3) further reduce the fatigue due to the weight of the Wiimote.

In the end, the shooting task in itself was within the reach of a large majority of the patients involved in the two studies but execution remained very slow. Thus, even though they knew the songs well enough to sing them if asked to, patients were unable to recognize the melodies when they played them. This task was likely too demanding for their abilities from the cognitive and motor points of view. We solved this problem with the addition of heavy rhythmic assistance in the Reminiscence Mode, which enabled all of the patients who tried it to play with a rhythm much closer to that of the original melody, resulting in much more powerful episodes of reminiscence which we discuss in Section 10.2.3.

10.1.2 Integration

While the most important thing for patients is that the game be fun, to appeal to caregivers it must primarily be extremely easy to use even without any training in computer science or music therapy. More specifically, the system must first be quick and easy to set up and robust enough to work instantly every time. It is obviously quite hard to give precise definitions of what quick, easy and robust mean in practice, as limits to what is acceptable always depend on many complex factors, of which level of impairment, environmental context and staff workload are just a few salient examples. For our purposes however, we agreed with healthcare practitioners on a general maximum setup time of 3 minutes and a maximum failure rate of 5%.

With our prototype, which was nowhere near as integrated and user-friendly as the new production version is, robustness was far better than required. We did encounter a few surprising bugs at startup but not even a single session was interrupted due to a system failure. We credit our constant focus on simplicity for this good performance, as it seems that using simple and mature tools kept us free of the unexpected errors that are almost invariably the flip side of the coin with brand new, high-end devices and applications.

As for setup time, the 3 minute limit was never exceeded as long as the audio and video systems were already in place. Indeed, at Saint-Maurice, the most time-consuming step was by far the installation of the projector and projection screen. When everything had to be taken out of the storage room and installed in the animation room, setup did take more than 3 minutes. This was not much of a problem since we were organizing group sessions which, with at least 3 and frequently 4 patients, always lasted more than an hour. However, had we used it for solo sessions, such a setup would have been completely impractical.

Thus, if, for instance, one is to move from room to room and conduct individual sessions with each patient, we suggest using a large computer-enabled TV instead, as we did for the usability study at Broca. This way, with just two cables connecting the computer and the TV, one for audio and one for video, one gets a fully functional system that can be moved around rather easily on a standard hospital tray. Furthermore, if such TVs are already in place in patients' rooms, as is increasingly the case due to significant price cuts for such appliances, the system can be up and ready in less than a minute, making it practical for even the busiest of healthcare practitioners.

Our second and most profound concern in terms of usability for caregivers was whether they would be able to manage sessions easily with the system. Of course, this includes the ability to configure sessions and navigate through song files, but given the sheer simplicity of the interface such things were unlikely to cause problems. Much more complex was the question of how caregivers would explain the purpose of the game to patients, ensure their safety, understand their mistakes, help them make adjustments, manage their potential behavioral issues and so on. After testing the system for the equivalent of about 100 individual 10-minute sessions, we can safely say that MINWii is very unlikely to raise specific issues that caregivers are not accustomed to. Both at Saint-Maurice and Broca, they were able to introduce the activity, identify what caused patients' difficulties and distress and provide help as they were used to doing.

We however did adjust two important features of our design and protocol to progressively make these support tasks easier than they were during the first sessions. Otherwise, it seems unlikely that MINWii could have been put to good use by any but the most dedicated and well-trained caregivers, which is the complete opposite of our goal. Here, again thanks to our early and recurrent testing, we were able to detect several patient management caveats and correct them efficiently. First, as we said earlier, we realized that patients would try to read any text displayed on the screen, even when specifically told not to bother. Thus, we decided to write everything in big fonts, including what was only intended for caregivers. Second, along the same lines, we hid all signs of complexity such as cables, auxiliary devices or configuration menus and options as much as possible so that things looked simple and natural to patients. These two things were the main causes of frustration and anxiety and working around them alleviated the need for caregivers to manage patients' outbursts. Once that was done, making things easier for supervisors mostly was a matter of better adapting the gameplay to demented patients, thus giving them more autonomy, which is the subject of the next point.

10.1.3 Autonomy

We have explained that instead of pursuing the seemingly unattainable goal of making MINWii playable autonomously by patients with an MMS under 20, we chose to include caregivers in the gameplay and at least partly rely on them for several features that a healthcare game must have, such as proper guidance and reward. For this reason, MINWii neither contains in-game instructions and tutorials nor explicit scoring and reward mechanisms, although the latter can be considered to be one of the implicit roles of the musical output. However, counting on the close involvement of caregivers does not mean that we should not try to make it easier for patients to navigate through the game and play it as autonomously as possible.

As with any other game, there is a clear tension between ensuring that MINWii is easy and pleasurable enough to play and making it challenging enough to give players a sense of achievement and empowerment. The peculiar part here is that contrarily to what is considered fun in a very large majority of commercial games, challenge, in our context, is not very appealing to players and can even be dangerously deterrent if it is too pronounced (see Section 10.2.2). Thus, we focused on maximizing ease of play and pleasure and tried to put in just enough challenge to keep patients interested and make them feel empowered to renarcissize them. It turned out that enough really was not much: we show how successful pushing this logic to its furthest extent was in Section 10.2.3. Here, we only address the reaction to the general gameplay elements that we included to move towards this goal of simplification, such as single focus gameplay, use of simple, large shapes with bright colors etc. that we cited in Section 9.2.

First, patients seemed to understand the purpose of the game very well in spite of their disabilities. The very good affordance of the Wii Pistol and the close resemblance of the virtual keyboard with the white keys of a regular piano most likely played a central role in achieving this. Second, as the generally low number of necessary verbal interventions shows (see Figure 10.1), patients rarely got stuck while playing the game, thanks to our making the course to follow extremely obvious with enlarged, brightly colored and shining highlighted notes contrasting with much smaller, dark gray keys on the rest of the screen. Moreover, when they did get stuck, often because the highlighted note moved too far and challenged their attention abilities, a little prompting from caregivers was usually sufficient to get them back on track. There were of course times when we had to re-explain the purpose of the game and show them where they were supposed to shoot, but except for one test subject who ended up quitting the experiment (see Section 10.2.2), these episodes of major confusion were rare and did not prevent the session from continuing eventually.

As Figure 10.1 shows, patients needed lesser and lesser help to complete their task in the usability study, which suggests that they were getting better at playing but also that the psychologists following them learned to give more efficient help, eventually intervening no more than 6 times during the entire session for 4 out of 7 patients. Moreover, physical help proved almost totally unnecessary for all but one patient, which shows that the actions we required from them were always within their reach in both motor and cognitive terms. We were worried about this at first when we tested the game at Saint-Maurice, as before the introduction of Reminiscence Mode we had to take patients hands in ours and aim for them quite often. But it

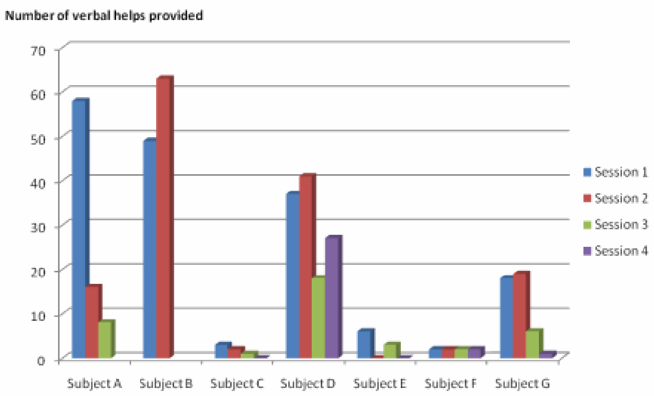

Figure 10.1: Number of verbal interventions by the psychologist.

turns out that it was simply because we were too impatient to have them hear the music with the proper rhythm. When given enough time, as they were during the usability study, patients were fully capable of completing the task on their own, albeit much too slowly from a musical standpoint.

Finally, the strong decreasing trend in the time taken to complete the sessions (see Figure 10.2) and, to a lesser extent, in the number of errors (see Figure 10.3), clearly demonstrates a powerful learning effect, even though patients rarely recalled having played before. This finding is consistent with the known fact that learning new motor and perceptual skills is possible in AD patients because it depends on procedural memory abilities, which are better spared by the disease [161]. Indeed, according to [162], in this kind of procedural learning skills are mastered without awareness, often simply by repeated exposure, and can be unconsciously revived from implicit memory[1]. Better yet, looking at the results for the last session, which was played autonomously, one can see that most patients were able to complete their task in roughly the same time as they did with help, showing that their learning did stick from session to session. We can consequently claim that our results are not merely a consequence of the psychologists getting better at helping and reflect actual progress by patients. This shows that MINWii is indeed well adapted to our target population, as it relies on abilities that are preserved well enough to allow patients to increase their skills through practice even without any recollection of the previous sessions.

10.2 Motivation and Fun

Although we are making healthcare-oriented "serious" games, our primary objective, at least prior to actual therapeutic validation, remains for patients

[1]This is one of the bases of the action of CST (see Section 8.2.2).

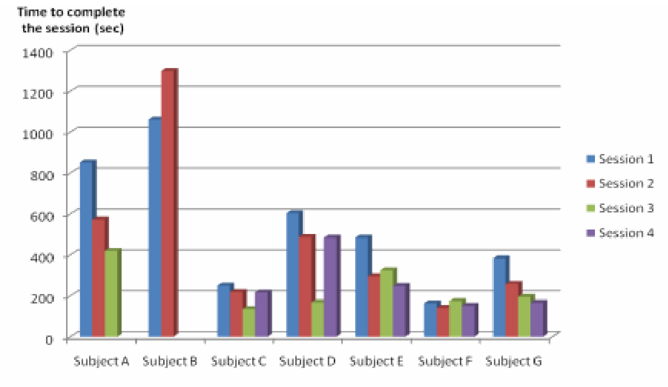

Figure 10.2: Time necessary to complete the session.

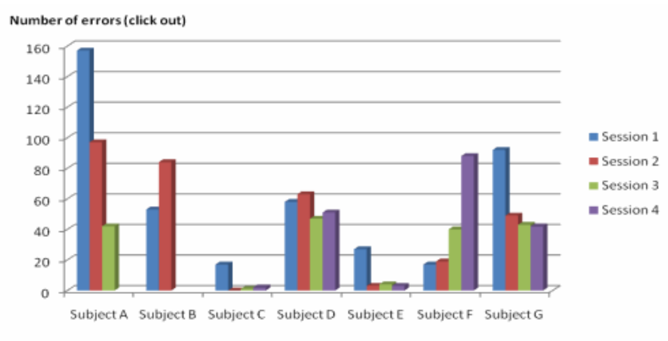

Figure 10.3: Number of errors (clicks out of the highlighted note).

who play MINWii to have fun. Indeed, if we achieved that goal, our game would already have a significant impact on their lives, since distractions suitable for our target population are not so numerous and often quite hard to implement, be it at home or in institutions. Once fun is guaranteed, we can try to assess and then enhance MINWii's therapeutic impact by altering the gameplay and protocol of use. However, modifying the game to meet therapeutic goals requires that we first clearly identify what makes it fun and motivating, in order to make sure that these fundamental characteristics are not lost when we try to make it more therapeutically efficient.

To this end, in this section, we review patients' reactions to the three main gameplay modes and try to understand what made them successful or not with which player profile. First, we discuss the Improvisation Mode and the acute need for guidance that most patients exhibited. Second, we focus on the risks and benefits of the Challenge Mode which, even though it proved quite demanding and thus disappointed many patients, could be highly beneficial for those who like it, precisely because it is so hard. Finally, we examine Reminiscence Mode, by far the most popular of all three, in detail to explain why we see this specific gameplay as a good basis for a first production version of MINWii.

10.2.1 Necessary Guidance

For the very first session, only the Improvisation Mode was available. We were thrilled to see that patients were willing to play when asked to, some of them even showing signs of great enthusiasm and rather surprising pointing skills for a first trial. However, none of them were willing to explore the system in depth on their own, let alone improvise. When invited to do so, they said things like "I don't know any music" or "Hum me some tunes" and never even tried to click random notes, shake the Wiimotes or click the corners of the screen the way most of the healthy subjects who tried the application during informal testing did.

Even though it is somewhat characteristic of demented patients, the extent of their unwillingness to experiment still surprised us. It is a well known fact that Alzheimer's disease and other forms of dementia, even though they hinder patients' motor and cognitive abilities, do not take away their creative intent, which they readily express in activities such as painting and sculpture, even though they sometimes need prompting from caregivers to do so. Consequently, we thought patients would also be happy to express themselves musically through improvisation, which proved completely wrong since we could not get even a single patient to try improvising freely.

A possible explanation is of course that we simply did not find the right interface design for patients to engage in free musical expression or that our choice to organize group sessions induced some sort of "stage fright" in patients[2]. However we think that these results are not the consequence of a mere design or protocol flaw but have more structural causes. Improvisation, contrarily to painting, is a real-time process, which makes it difficult for patients who are typically slowed down in their movements and cognition. Furthermore, since music has no direct figurative capability, or at least far less than painting or sculpture, it is extremely difficult to find something for patients to root their improvisation into: there is no simple equivalent of "draw your house" or "mold a vase" with music.

Nevertheless, when we suggested a song they remembered, patients were more than happy to try playing it with the improvisation keyboard. Of course, even though one of them needed no help at all (she was a former pianist and had a rather high MMS rating of 22), the others were not able to play a song without extensive assistance from a musically trained caregiver, here Dr. Péquignot. Furthermore, besides the pointing issue, and although 8 or 11 notes are more than enough to improvise, many of the songs that patients would have liked to play did not fit into a single scale. Thus, improvisation does not appear as the best basis to design a game aiming to provide untrained caregivers with a tool to have demented patients play with music in a fun and easy way.

That does not mean that this mode should be discarded altogether: interesting results can still be obtained under the close supervision of an experienced caregiver. First, properly trained music therapists may be able to get patients to overcome their fears and begin experimenting with the system. Second, all patients are different and we did encounter at least one test subject whose preferred interaction mode was this one. Finally, improvisation clearly was the mode of choice for healthy subjects during informal testing and, as such, is likely to be the most appealing for demented patients' visitors, especially children. Consequently, we think that improvisation should remain in MINWii, if only for the few patients that will prefer it, and should be experimented with by experienced music therapists, but we will nevertheless focus on the enhancement of the other modes for the first production release.

10.2.2 Risky Challenge

In Challenge Mode, which was introduced shortly after the Improvisation Mode, at least in its first, naive version, patients could play a song without needing help to find the right notes to click on. We felt we were on the right track because patients were much more comfortable following the highlighted notes than trying to create something on their own and would then clap, sing and start reminiscing more and more often. They were overall clearly

[2]Stage fright was probably part of the problem indeed, but since patients seemed much more concerned by our judgment than by that of their peers, solo sessions would most likely not solve this issue.

Subject	Satisfaction score (/28)	
	1	2
A	20	18
B	16	10*
C	21	19
D	15	16
E	17	24
F	18	20
G	16	18

Figure 10.4: Satisfaction scores at sessions 1 and 4.

having fun, as shown by their answers to the satisfaction questionnaire in the usability test (see Figure 10.4). However, in Challenge Mode, failure remained rather likely due to the relative difficulty of shooting fast and accurately. Thus, playing the song from start to end still demanded quite a lot of time and became rather frustrating without active physical help from a caregiver, as patients otherwise had a lot of trouble following even simple rhythms on their own and were thus unable to recognize the songs.

Here again, most patients did not seem to be excited by the challenge in itself, which makes sense since they are used to failing at even the simplest tasks and thus develop a tendency to avoid any potentially difficult enterprise. In fact, although it was somewhat easier to convince them to try the game out when we had songs to propose instead of just improvisation, many ended up quite frustrated by this mode. The worst case was the patient who quit the usability study because she experienced great difficulty with the gameplay. She repeated several times that she used to play a lot of music when she was younger and that what we were offering was far too rudimentary to be interesting and would teach her nothing. This shows (1) that trying to entice demented patients with challenge is quite risky and (2) that MINWii and other musical games, although it may seem surprising at first, are not necessarily suitable for musically trained patients. Even with the best assistive algorithms the musical result will be rather poor compared to what they used to be capable of and thus will have the opposite effect of what we want, reminding patients of their illness instead of empowering them.

In spite of all these flaws, Challenge Mode had its fans too. One particular patient was clearly motivated by the shooting task in itself and cared very little for the music. He kept referring to himself as a cowboy and often made jokes about how fun it was to kill with a toy gun. He even commented that “in war, he who does not kill first gets killed”, which carries an obvious sense of danger and urgency and suggests that he was actually thrilled by the challenge that we proposed. He even was enthusiastic enough about this to convince his room neighbor to join our testing group by telling him how fun it was to shoot like a cowboy.

This behavior, and that of at least another patient who seemed strongly motivated by his self-imposed goal of playing as fast as possible, convinced us that Challenge Mode could be worth keeping in the final release. Indeed, in the end the reason why patients play the game does not really matter and does not necessarily have to have anything to do with music. Thus, we decided to continue refining this mode despite its somewhat poor general reception. It is included in the first production version of MINWii to appeal to this specific challenged-oriented type of player, even though we will have to warn caregivers to use it with caution to avoid frustrating less adventurous patients.

10.2.3 Powerful Reminiscence

Reminiscence Mode was introduced last because it provides a lot more assistance than the two previous modes and thus required much more work and pretesting. Its most important feature is the rhythmic assistance that makes it possible for patients to play easily, up to the point that they merely have to vaguely point the pistol at the screen and shake it from left to right to play through a song they love.

We were worried that such an easy task might deter our test subjects by making them feel underestimated, but we were completely wrong. None of the patients ever said the task was too easy. Despite the very low difficulty of the gameplay, even elderly people without any signs of dementia who happened to pass by during our sessions seemed rather proud to be able to play a song. We think this is because, for people who were born in the 1920s, any task involving computers is often seen as utterly complicated. Therefore, being able to do even the simplest thing with something so "otherworldly" as a Wiimote is considered an achievement. Just like with human help, it is hard to say whether patients were unaware of how much assistance they got from the system or simply did not care, but playing MINWii in Reminiscence Mode clearly was more enticing than Challenge Mode for most.

This observation is crucial: it seems that no matter how easy we make our games, demented patients will still feel empowered when playing them. We can therefore really tailor our system to support reminiscence as much as possible without having to worry about the gameplay becoming dull. This is very important because patients are usually well aware that they forget things more and more rapidly over time and often seem ecstatic when they discover that they do remember the songs from their childhood. With MINWii, we have shown that we could easily trigger this kind of musical reminiscence even in the most disabled patients without the help of a trained music therapist. According to us, this proves that renarcissization at home through music is a sensible idea. MINWii would act on two different levels by (1) giving a sense of achievement through its gameplay, offering patients an opportunity to appreciate the motor and attentional skills they still have and (2) stimulating patients' musical recollection abilities, showing them that their memory is not nearly as unreliable as they thought.

Furthermore, the musical memories that come back often trigger a train of other flashbacks, with quotes such as "My husband was a trumpet player; he often played this when we went to the ball; these were happy times" or "We sung this at X's wedding; how much fun we had back then!". These recollections usually seem to be even more pleasurable than the singing itself and can sometimes lead to signs of completely unexpected awareness. For instance, one severely disabled patient (MMS = 10) told us, after playing a song by a famous French singer a few weeks in a row, that she was sad because he was very sick at the time, maybe about to die. The caregivers were astonished that a patient with such a high cognitive deficit was able to understand and retain this complex bit of current news while she practically spoke about nothing besides the Holocaust when she was not participating in MINWii sessions.

However they did not take the opportunity to congratulate this patient, preferring to help her overcome the sadness that these evocations of sickness and death for someone much younger than she was caused in her. Events like this further justify the presence of caregivers at all times while the game is being played in order to smooth out the impact of such highly emotional occurrences. Yet, this anecdote also illustrates the tremendous potential of music therapy, which can have unanticipated, very profound cognitive effects [4], far beyond its usually accepted benefits regarding anxiety relief and memory stimulation [139].

10.3 Human Contact

Our last key design point is human interaction: MINWii is tailored to encourage patients to interact with their caregivers and family members as well as with other players. Indeed, patients told us praises such as "You're all so nice: it's a pleasure coming here", "Thank you for singing with me: you're a much better singer than I am" or even "For people as lonely as I, human contact is very precious". Although this aspect was not a primary focus in the beginning of the design process, such remarks led us to reconsider our system not only as a game, but also as a medium for interaction.

To see how MINWii supports human contact and find ways to improve it in this regard, we first examine the effects of caregivers' constant praising of patients' performance and efforts to see how MINWii could further enhance communication and comprehension between them, since this kind of interaction becomes more and more central in a patient's life as the illness progresses. Then, we consider the benefits of having group sessions to help patients socialize with each other and collaborate musically. Finally, we discuss the appeal of the game for visitors and see how it could be used to strengthen the bonds between patients and their family.

10.3.1 Praise

In order to keep MINWii as failure-free as possible, we chose not to include any kind of explicit scoring or reward system. As explained before, we rely thus rely solely on the caregivers supervising the session to give praise for patients' efforts and performance. This role is extremely important and serves multiple purposes, the first of which is simply motivating patients to play. Indeed, with their executive deficits demented players more or less always need someone to spur them to take part in an activity and prefer or maybe have no choice but to remain idle if they do not receive any encouragements. Thus, we tried to understand how caregivers could best convince patients to give MINWii a try. It turns out that the answer is fairly simple: insisting on the failure-free nature of the task while offering to sing along to make play a collaborative effort works best.

Once the game is started, caregivers need to continue giving praise to keep patients motivated and focused. This was very clear for one patient in the usability study who was always looking for approval from the psychologists. She did not seem to take much pleasure in her successful playing until she was actually praised, making validation fundamental for her to fully enjoy the activity and again showing that the presence of a caregiver is absolutely necessary to ensure a renarcissizing effect on patients. One could argue that MINWii then does not add much value to the process since caregivers could simply renarcissize patients by praising them for whatever they are doing at the moment. However such things have been tried in the past and do not seem to work very well [139], in part at least because patients have to agree with the compliments for them to have a positive effect on their state of mind. MINWii provides a great number of opportunities for such praising because it puts patients in a situation where they are more or less bound to succeed but still feel a sense of achievement, which can then be confirmed by caregivers.

We hope this process of renarcissization through praise will have a significant impact on patients' mood, but it should also have a positive impact on caregivers. We think that tightening their bonds with their patients by giving them a more positive picture of their illness and encouraging them to share a fun activity together will spur them to go out of their way to help those of whom they are in charge. Indeed, even if it is not MINWii's primary purpose, the effect of enhancing caregivers' mood and renewing their motivation with a novel, fun activity certainly should not be overlooked. Caregiver burden and exhaustion is one of the biggest issues with dementia and countering that with innovative and exciting new tools and approaches could significantly improve patients' quality of life by improving that of their caregivers.

10.3.2 Socialization

Many patients rarely get visits, and the people they see the most are those treated in the same institutions, be it in day-care or long stay units. Just like other people, they chat, take walks and develop friendships, but their illness does make things more difficult, as they have trouble remembering faces and having coherent discussions. Thus, to see if we could enhance their interaction with MINWii, we chose to organize our sessions in the hospital animation room with groups of 3 or 4 patients in front of a big projection screen. This was a tough choice to make since, given how easy it is to set MINWii up, it would have been much easier for us to plan one-to-one private sessions, as we did for the usability study, albeit for other reasons. Indeed, demented patients, who have a blurred perception of time, are quite reluctant to leave their room for fear of missing a visit or a meal, even when they have just been told that nothing is up for them in the next 4 hours. This kind of behavior, on top of demanding more efforts from our part to convince patients to join the sessions, resulted in refusals to participate, even from patients who had a lot of fun with MINWii the week before.

Nevertheless, our experiment showed that we were indeed able to have patients cooperate in musical production. Since Alzheimer's disease greatly hinders their multitasking abilities, it is rather hard for the person playing to sing the song at the same time, even though the two tasks are very easy if taken separately. Having group sessions made it possible to still have patients sing by encouraging an "I play, you sing" dynamic in the group. We were happy to see them discuss musical preferences, clap and congratulate each other after playing or even, in a few cases, encourage other, more reluctant patients to come to the sessions and play music, as we explained in Section 10.2.2.

We think our tests demonstrate that group sessions can be a very useful tool to use with patients who have difficulties socializing with others or simply to motivate those reluctant to give the game a try by showing them that their friends have fun with it. Nevertheless, they pose a variety of challenges and are not adapted to all situations. First, taking care of 4 patients at the same time is obviously more demanding than taking care of just one. Since the more or less constant attention of one caregiver is necessary to ensure a positive gaming experience for the patient playing, we advise to try to have two people to watch over group sessions: one assisting the player and one taking care of the other participants. If that is not possible, the person in charge of the activity will have to make sure that the patients coming do not have too many behavioral issues as having to constantly attend to the needs of those who are watching may easily ruin the experience for everyone. Second, the use of Challenge Mode would be tricky in such a situation, as it could both underline patients' difference in skills, frustrating those who cannot achieve the same performance as their peers, and create a dynamic of competition, while our aim is not to organize a contest but to have patients collaborate musically to strengthen their bonds.

10.3.3 Visitors

MINWii's very flexible gameplay, which can be adjusted from quite a serious challenge to an extremely simple task, gives it the ability to appeal to many audiences besides demented patients. More specifically, several informal tests have convinced us that, if children visit, playing with MINWii could be a lot of fun for them and would constitute a very good way to encourage interaction with demented patients, mainly through singing and clapping. And anyone who has observed elderly persons a little bit can tell that hardly anything could top the pleasure they take in spending some quality time with their great-grandchildren.

In any case, the very positive reactions we got from healthy test subjects of all ages led us to think that MINWii could add a little pleasure to their visits by giving them something fun to share with their disabled parent or friend. Moreover, just like its effect on staff, MINWii should enhance visitors' mood by giving them a much more enjoyable picture of demented patients. Music and especially music therapy are indeed often praised by relatives as a key to almost bringing back patients former self, which is always very soothing for those who visit as it helps them cope with anticipatory grief.

Again, this should in return have a positive effect on patients. If they get more visits and see that their visitors do not look down on them, thanks to the musical sensitivity and playing abilities they can still exhibit with MINWii, their mood should improve and, hopefully, their behavioral disorders calm down.

Chapter 11

Conclusion and Directions for Future Research

With two complementary series of tests in real clinical environments, we have designed MINWii, a free, open-source, Wiimote-based musical game targeted at demented patients with mild to moderately severe cognitive impairment. We have also proven its adequacy as an occupational tool usable in institutions or at home under the supervision of caregivers without any musical training for a very small cost.

In this conclusive chapter, we first review our results and use them to justify the previous claim. Then, we detail the future research we intend to undertake now that MINWii has reached a more mature stage, with the release of its first production version. Our main focus will be lasting renarcissization for the reduction of anxiety, depression and behavioral issues through the large-scale diffusion of the game, supported by controlled studies finally proving beyond any doubt the efficiency of music therapy for the enhancement of demented patients' quality of life. Afterwards, to conclude this case study, we move on to longer-term objectives and discuss MINWii's therapeutic potential beyond its expected effects in terms of quality of life, with additional potential therapeutic powers that will require specific studies once MINWii's renarcissization capabilities are proven and put to use in the healthcare community.

11.1 A Successful Occupational Tool

Before aiming for an actual therapeutic impact, our first milestone was to create a game adapted to our target population and validate it as an occupational tool that could be used by animation staff in hospitals like Saint-Maurice to provide new and exciting ways for demented patients to pass the time and remain as active as possible.

In this first section of the conclusion, we summarize the results of our tests to show that we indeed reached this primary objective with MINWii. First, we address usability issues and show that our system boasts a sound design that is well-adapted to its context of use. Second, we demonstrate that our "serious" game really is an actual game, in the sense that, regardless of its long-term purpose and impact, most if not all patients can and do have fun with it and want to keep playing. Last, we examine MINWii's role as a social facilitator which, because of the many remarks made by demented patients regarding this matter, we have come to see as almost as important as the fun itself, especially within the framework of our Action Research-inspired methodology.

11.1.1 A Sound Design

We have met our three main usability criteria with our game:

- MINWii uses only off-the-shelf hardware that can be bought in any video game store and the production version can be downloaded for free by anyone with access to the Internet[1]. A complete system can thus be set up for less than $1000, going as low as just $60 for a Wiimote, pistol and wireless sensor bar if the computer and TV are already available, which is often the case.
- The system is very easy to setup in its production version and has already been put to good use in real therapeutic environments by healthcare practitioners with little to no musical training. It should consequently integrate easily into most demented patients' treatments, be it at home or in specialized institutions.
- The pointing mechanism and visual interface have proven instinctive and easy to use for up to moderately severe patients, which sets MINWii apart from most other dementia-oriented applications, which usually target only patients with very mild impairment. Moreover, the clear learning effect demonstrated in the usability study proves that our game is very well adapted to the latent abilities of demented patients, who can gain mastery without even being aware of their progress.

Thanks to these assets, we think that using MINWii as an occupational tool can rightfully be considered with a large majority of demented patients in virtually any environment.

11.1.2 A Fun Game

MINWii's goal, for this first phase, was simply to allow demented patients to have fun with music in as wide a variety of contexts as possible. Three key observations show that we indeed reached that goal:

[1] See www.minwii.org.

- MINWii successfully engages the musical sensitivity and abilities of patients, who were invariably seen singing, clapping and congratulating each other for good playing. Moreover, specific modes and levels of difficulty make it able to appeal to somewhat unusual demented players who may want more freedom or enjoy a bit of challenge.

- Players almost always feel greatly empowered when they realize that they can indeed play the game and have fun with it. This is especially important when looking at Reminiscence Mode which, at first glance, might look too dull to be called a game, but in fact was by far the most popular among patients, who expressed their pride of being able to make music no matter how much assistance was provided by the program.

- MINWii triggered numerous and often surprisingly detailed and coherent episodes of reminiscence which at times far exceeded the supervising physician's expectations based on patients' level of impairment as measured by their MMS score. These recollections were obviously very pleasurable and greatly participated in the fun and empowerment provided by our application.

We think this qualifies MINWii as an actual game for demented patients, which in itself justifies our efforts. Moreover, it ensures that any further study and use of the game will at least let participants have a good time with music, regardless of the actual therapeutic impact of MINWii which, even if we are confident that it will be positive, still remains to be methodically and thoroughly assessed.

11.1.3 A Social Catalyst

Contrarily to our first case study, since MAWii's main objective precisely was to encourage children to communicate through music, fostering social interaction was not a primary concern during the design of MINWii. However, the always astonishing power of music to create and tighten bonds between people, coupled with demented patients' acute need for human contact, made us realize, in the course of our experiments, how important the matter was and how much MINWii could do in this regard:

- Our design gives a crucial role to caregivers who of course have to set up and configure sessions but, much more importantly, act as an explicit reward mechanism, which we purposefully left out of the game itself, by giving praise for a patient's efforts and, if applicable, good performance. By offering caregivers a very good occasion to congratulate demented players, who are more or less bound to succeed in performing the song of their choice thanks to our highly assistive gameplay, MINWii strengthens their bonds with their patients, who thus feel better considered and cared for.

- During group sessions, MINWii supports meaningful interaction and even collaboration between patients. Beyond clapping, congratulations and discussions about what to play next, the "I play, you sing" mechanism that emerged during the iterative testing phase again proved very pleasurable. Patients who were too focused to sing while they were playing were very eager and happy to do so when they were not in charge of the controller.

- Visitors, who, if they happened to be there at the right time, were systematically invited to come see their demented parent or friend play, as well as informal testers were almost unanimously enthusiastic about the game. MINWii should thus be a very good way for patients to bond with their family and friends by sharing a fun musical activity.

Although some of our design choices, such as the absence of a congratulation system akin to that of *Guitar Hero*, were made with that goal in mind, our conclusions about fostering human contact mostly pertain not to MINWii itself, but to how it should be used. Caregivers should see it as way to interact and praise patients and put little emphasis on performance. They should also organize group sessions whenever possible to develop patients' relationships and save time. Finally, families should be encouraged to play with their demented parent when they visit, as MINWii is, before anything else, a recreational activity enjoyable for both parts.

11.2 Lasting Renarcissization

Now that the first mature version of MINWii has been released as an occupational tool, we intend to focus on validation and diffusion for our initiative to have an actual impact on the well-being of as many patients as possible. To this end, we first plan to assess the actual therapeutic impact of renarcissization with MINWii through multiple controlled studies in various contexts. We hope that positive results will help us promote home use and build a community around our game in order for it to reach a large audience and start evolving and improving outside of our team.

11.2.1 Controlled Studies

If we want to prove that MINWii does have therapeutic value, we must switch to a new approach and organize random controlled studies with larger samples of patients. Our first focus in this new phase will be the process of renarcissization and its impact on the overall quality of life of both institutionalized and day-care hospital patients. We hope to show a direct link between weekly use of MINWii and the reduction of depression and behavioral disorders, which should in turn induce a measurable delay in institutionalization for day-care patients.

We will hopefully be able to conduct three studies in three different contexts:

- One with patients in intermediate stay at Broca Hospital, which would measure the effect of bi-weekly sessions on depression, most likely using the Cornell scale[2] [163].

- One with day-care patients at hospital Broca, comparing the levels of anxiety and stress of players and non-players through measurements of cortisol in their saliva [164], [165].

- One with other day-care patients attending a memory clinic run by Isatis[3] which would look directly at quality of life and delay of institutionalization.

All of the studies would be controlled by comparing patients using MINWii with patients participating in another activity, most likely group listening of patients' favorite pieces as chosen by them or their family, for the same amount of time under the supervision of the same team.

We hope that these studies will help establish the potency of music therapy as an efficient complementary intervention for dementia. Indeed, although its positive effects have long been hypothesized and hinted at by many previous works, meta-analyses invariably conclude that the lack of a sufficient number of proper studies makes it impossible to rightfully recommend music therapy for the treatment of dementia. We think that MINWii, by (1) enabling caregivers with no music therapy training to use active music making with demented patients and (2) automatically collecting data about their performance for computer-assisted analysis, could give us the means to finally conduct studies on a scale large enough to reach definitive conclusions within the always very limited research budgets that support the work on treatments deemed as auxiliary, such as music therapy.

[2]The Cornell Scale for Depression in Dementia was developed specifically to assess major depression in demented patients who, because of the severity of their condition, may give unreliable reports, by including additional information given by the person's caregiver, similarly to what is done in the QoL-AD (see Section 8.1.2).

[3]Isatis is a French organization that, thanks to public subsidies, offers financially accessible adapted housing for elderly people, with various levels of medical services ranging from simple daily check-ups with a physician to full-blown medical assistance comparable to that of a hospital's palliative care unit.

11.2.2 Home Use

Although our studies will necessarily have to be conducted in institutions, as working directly at patients' homes would be impractical, our primary objective of delaying full-time institutionalization implies that MINWii can be used at home. Of course, its efficiency will most likely be lower when used solo at home with a family member or personal assistant than when played in group sessions under the supervision of a trained therapist. However we think these two ways of using MINWii are complementary, as patients who enjoy it at their day-care center should be glad to bring it back home. Moreover, similarly to what we have already said about visitors in institutions, we hope that our game can work as an incentive for families and friends to come visit demented patients by making the time spent together more fun and by showing them a much more enjoyable and soothing image of their loved one.

Our choice to use only cheap, off-the-shelf hardware will serve our pursuit of such widespread home use. First, demented patients who still live at home are more or less bound to own a large TV to which the system could be hooked up, as we did at the Living Lab at Hospital La Collégiale. Second, they are more and more likely to have a computer too, since prices of laptops have recently hit an all-time low. However if they do not, which is still the case for a majority of demented patients, with its very low hardware requirements, MINWii can be used on a rather old computer, for example one that a family member would otherwise throw away. With these two pieces of equipment available, setting up MINWii only costs about $60 for a Wiimote, a pistol and a sensor bar, a price tag that should be low enough to appeal even to families without many financial resources. Indeed, MINWii will offer a very good return on investment even if it spares just one week of institutionalized care, which in France costs at least $200 to the patients themselves, the most part of the costs being covered by mandatory national health insurance.

In spite of this easy setup and likely very high return on investment, if we want MINWii to spread in homes we must reach out to the public at large. We will thus try to present our game in large public events where we will show promotional videos, discuss feedback from early adopters and invite people to try it out. On top of increasing awareness about our project and thus maximizing MINWii's penetration, we hope that our demonstrations will help change the often very negative view of the public towards Alzheimer's disease and dementia in general. In particular, we intend to show that demented patients can still be lively and fun to be with if put in the right environment with proper activities that can be shared by all, such as MINWii. Indeed, our opinion is that what really makes patients the saddest is to see themselves as a burden for society, which always reflects a very bad self-image at them, since they are not capable of doing this, need help do to that, must live secluded in specialized care centers etc. We think that if we manage to change this, the life of elderlies with diminished cognitive and motor capabilities could most likely be almost as fun as the life of four-year-olds, who are greatly limited in the cognitive and motor areas too and do not seem to mind very much!

11.2.3 Building a Community

We want MINWii to spread, but we also want it to evolve to adapt to the very diverse needs of demented patients and their caregivers worldwide. Therefore, we want to build a community around our game, gathering patients and their families, physicians, healthcare practitioners, institution administrators and specialized caregivers, equipment providers, developers etc. to exchange feedback and ideas, propose and implement evolutions and overall collaborate on any kind of project involving MINWii.

Our specific interest here is the *crowdsourcing* of the development of the game, which will be necessary as we will not be able to implement all the minute modifications that will unavoidably have to be made to adapt our tool to new therapeutic, environmental or cultural contexts. We can cite three characteristic examples of tasks for which we need the help of the community, in order of increasing complexity:

- The easiest but likely most crucial and time-consuming task would be the constitution of a large database of songs from which patients could choose. Indeed, the newly released production version of MINWii can import any musicxml file, which gives it great flexibility. However very few songs can be found easily in this form, which is why we hope to gather all the files composed by caregivers for their patients' specific tastes and make them available to all[4].

- The next step would be the customization of MINWii for other cultural backgrounds. Up to now, one can only play French songs with Western classical instruments, which is very unlikely to appeal to and trigger reminiscence with, for example, South-American or Asian patients. We need people who treat patients from these cultural backgrounds to add the relevant instruments and songs that will let them explore their musical past.

- Finally, a more long-term project could be the adaptation of MINWii for tactile tablets such as Apple's iPad [166]. Even if the end-result would certainly be quite different in terms of gameplay and would thus

[4]MINES ParisTech will play a crucial role in the MINWii community by taking care of legal issues such as licensing. Hopefully, artists and copyright owners will grant us permission to make such non-commercial, therapeutic use of their songs for free.

require specific testing and therapeutic validation, the capacity to generate fun and trigger reminiscence is likely to remain. This would make it possible to distribute MINWii along with the now booming integrated computer solutions for elderly patients' homes and specialized institutions, which almost always rely on tactile devices.

In order to support the MINWii community, we have built a website which we will continue to develop in order to attract new users and encourage them to share their ideas, adaptations and best practices in an easy way. It will contain installation and user guides, tutorial videos, extra songs and instruments and just about anything else that could be useful for MINWii users. Just like reaching out to the public, we see this as an integral part of our Action Research methodology, in the sense that a better diffusion and overall impact on the community will attract more users, allowing us to gather more data and enhance the software further, starting a virtuous circle of growth for our application.

11.3 Added Medical Value

Our primary objective was to create a game that would let demented patients have fun and express themselves with and around music. We have shown that this phase was successful and are moving on to the next step, which is to demonstrate MINWii's renarcissization potential and put it to use to enhance demented patients' quality of life, in particular by acting on their mood, self-esteem and behavioral disorders. However MINWii could offer yet much more than that on a longer time scale, mostly thanks to its adaptable design and its data gathering capabilities.

In this section, we briefly touch on three potential long term benefits of MINWii that we see as the most salient and thus want to keep in mind during future developments, even if they are not yet a primary focus. We first examine MINWii's potential cognitive impact, which would require yet another, even larger controlled study with the current design. Second, we look at assisted diagnosis, which would imply the development of automatic log analysis tools and new, large-scale validation experiments. We then finish with adaptation to other pathologies, which would most likely rely on an extensive redesign of the gameplay but could nevertheless, in our opinion, be much more efficient than designing a new game from scratch.

11.3.1 Cognitive Benefits

In the treatment of dementia, based on current, indisputable knowledge at least, it remains impossible to reverse the cognitive decline in all but very few cases. Thus, whatever they might be, MINWii's cognitive benefits will only manifest themselves through a subtle slowing down of the deterioration of patients' abilities. This does not mean that it is not a goal well worth pursuing, since as little as two or three MMS points can mean a world to a demented patient, especially if his or her family is considering institutionalization. However, any study aiming at finding such a weak, second-order effect will necessarily have to involve a very large number of patients to reach the necessary statistical power. This is the main reason why we do not yet focus on this matter: only if and when MINWii is well established and widely used will we be able to conduct such an investigation, most likely by aggregating data collected independently in many different institutions using MINWii for renarcissization purposes.

According to recent evidence, the best candidate for treatment among the various cognitive functions impaired by dementia would be attention. That is at least the position of the makers of SGCogR, a game targeted at patients in the very early stages of dementia, who are using Posner's Attention Network paradigm [167] to design a pointing gameplay which would hopefully improve attention in players. They draw inspiration from [168], which demonstrates the positive effects of playing action games on the attention capabilities of healthy subjects. Because MINWii relies on the same type of pointing mechanism and attention shifting between highlighted notes, it could have a similarly positive impact. However since (1) SGCogR itself has yet to be validated and (2) our target patients are much more significantly impaired and thus less likely to be able to learn new attentional compensation skills, assessing MINWii's capabilities for cognitive improvement is not a priority for now.

11.3.2 Assisted Diagnosis and Orientation

One of the great assets of computers and video game technology from the point of view of healthcare practitioners is that such devices can automatically collect, process and display a lot of interesting data. In the case of MINWii, the simple statistical treatment that we applied to basic data that was automatically saved by the system such as completion time, number of errors etc. already provided very interesting results, most notably regarding the clear procedural learning effect that we demonstrated. One could easily imagine extending this kind of analysis by looking at other, more complex data series, such as pointer speed or click distribution, and applying much more complex statistical tests or even feeding the measurements into an artificial player model. Furthermore, extra tasks and gameplay variants could be added to engage specific abilities in a way designed to provide relevant and accurate informations about the players.

The likely goal of such an effort would be the creation of a tool to help with diagnosis, classification and orientation of patients according to their measured abilities and behavior. Here, using a system such as MINWii would have two clear advantages:

- Tests like the MMS are often long and boring for both patients and healthcare practitioners. Moreover, uncooperative people make this kind of assessment impractical and unreliable, as one needs patients to try their best and give honest answers to get an accurate evaluation. Thus, using a game would be very beneficial: it would not require as much involvement from caregivers because tasks would be graded at least in part automatically and the test would be more enticing for patients, who would likely be less inclined to resist the process, yielding more accurate results.

- Many tests require quite a lot of interpretation on the part of the physician or psychologist administering them. This often leads to significant variations in the results and thus implies that at least two different people must administer the test to get more reliable results. This makes the collection of such evidence even more impractical, which is why evidence-based practices are still very rare in the clinical world. With an automatic data collection protocol and a deterministic analysis of the results, MINWii would avoid these two issues, albeit of course at the cost of the sensitivity to context that human scoring provides.

Classifying patients solely on the basis of their performance at playing any game, no matter how well designed, would be preposterous, but making such a tool available to physicians would certainly help them move towards more evidence-based practices. However a proper assessment of MINWii's capabilities in this regard would require extensive trial and error to design the grading algorithms as well as a very large scale study involving numerous patients of all types to validate them. Consequently, even though we see great potential in such an approach, we again will only feel justified in pursuing this goal if and when MINWii becomes clinically mature enough so that we can base our investigations on a large database of patients' performances and on feedback from experienced caregivers familiar with the software.

11.3.3 Extension to Other Pathologies

The final development we have in mind for MINWii would be its adaptation to different pathologies. Indeed, many illnesses cause certain symptoms that resemble those of dementia, which our game was specifically designed to accommodate. For example, stroke patients may share the same attentional or motor deficits as demented patients, which means that MINWii could be useful for their rehabilitation. Similarly, patients suffering from Parkinson's disease may enhance their motor control and coordination by playing MINWii, with the music motivating and even guiding them, hopefully achieving the kind of dramatic results described in [4].

Using MINWii in the treatment of these new pathologies would likely require a significant redesign, the rehabilitation of a stroke patient for example being much more performance-oriented than the pure fun and reminiscence approach we have chosen for now. One would have to add a clear, explicit scoring system with tracking from session to session as well as room for much greater progress and mastery than what demented patients could conceivably achieve. However we think that most of the interface could be kept as is and adapted simply through the adjustment of parameters that are already changeable on-the-fly, such as tempo or highlighted note inflation ratio. Moreover, a large part of the knowledge gathered during the design of MINWii, especially in terms of usability for caregivers and attentional and motor burden, should be transferable to this new task.

All in all, it seems likely that users will find plenty of ways to modify our game in order to use it in the treatment of other, not necessarily so similar pathologies. We think that our choice to rely exclusively on free software will enable and encourage them to do so, so that our software can be reused in other contexts and, hopefully act as bridge between patients suffering from different conditions who, given their very different abilities, often have trouble communicating and collaborating.

Part IV

Design Recommendations for Therapeutic Music Games

In this final part, we compare our two case studies and try to infer general guidelines for the design and implemention of healthcare-oriented music games. Some of them restate well-established best practices from related fields and simply validate their transferability to music therapy game design. Some others, to the best of our knowledge, are nowhere to be found in the literature, at least in the way we present and apply them. Consequently, they should be taken with caution, since we have validated them in no more than two different contexts. That is obviously a rather general rule for guidelines deduced from a small number of case studies, but it is especially true in healthcare game design: minute details can make or break a gameplay, which is already a big issue for the makers of traditional games but can have much more serious consequences in a clinical context.

Nevertheless, we think that turning our exploratory research into a set of practical recommendations for music therapy and, hopefully, healthcare game design in general can greatly ease and speed up the development of similar software targeting other techniques and pathologies. Thus, first, we examine common sense rules and general best practices from the domains of music therapy and game design to see how they can be applied in our specific context. Second, we make the case for an Action Research-based methodology, which was a key asset in obtaining the actual user evaluations that so many initiatives in our domain lack and, in the end, resulted in much better products. Finally, while video games become more and more complex as the performance of machines and the expectations of ever more experienced gamers rise, we advocate for simplicity in healthcare game design. We try to explain how one may go about designing it into a game, even though it is so elusive and hard to define, which is probably the reason why our first prototypes were always far too complicated in one sense or another.

Chapter 12

Building on Knowledge from Video Games and Music Therapy

As we explained in the first part of this thesis (see Section 1.1.1), serious gaming is all about motivation through fun. Since this process is also a core component of both traditional video games and music therapy, although arguably not as central in either case, its seems logical that much knowledge be transferable from these two domains into our own. In this chapter, we explore these links and show that many widely accepted best practices from both the video game and the music therapy communities can readily be applied in our context, albeit sometimes with a few precautions and adjustments.

First, we examine the now classical game-maker's approach of population-centric design for a rewarding experience which, unsurprisingly, is also important for music therapists, albeit to a lesser degree. Indeed, and that is our second focus, music therapists often go much further and tailor their interventions to fit the individual needs and preferences of patients, whom they all consider as irreducibly unique. Again, the booming trend of ever increasing customizability in games shows that this need for uniqueness is also acknowledged in the gaming community, although game-makers are not nearly as advanced as music therapists in this regard. Last, we explore the issue of solo versus group activities, which this time seems equally central in the gaming world, with the rise to prominence of online games, and in the music therapy world, where deciding between solo and group sessions for a patient's treatment has always been a major concern.

12.1 Population-Centric Design

In the beginning, video games used to be like most works of art, designed and implemented quite freely with little consideration for marketing techniques or even with no commercial agenda at all. Nowadays, the video game industry has become much bigger and more competitive and marketing is so pregnant that no plan for a new game could conceivably fail to include at least a definite primary target population, such as girls aged 8 to 10 with a love for horses.

Thus, recommending a thorough study of the target demographic for a population-specific design is really nothing new. However this very simple rule has very specific implications in our context because patients suffering from the same condition or under the same kind of treatment arguably share much more pressing needs and desires than the usual target groups defined by market experts. We consequently propose the following set of specialized guidelines:

1. **Make a thorough medical review of the different pathologies and disabilities commonly present in the target population.** This is mandatory because medical conditions have strong implications in terms of design that are often hard to predict. For example, impulsive children have great difficulties with planning and projecting themselves into the future, and demented adults are afraid of complex activities that they sense they might fail at. Thus, members of both populations have a strong tendency to very quickly reject new devices that do not work right away, albeit for very different reasons: the former are not motivated enough to focus on learning how the device works because they do not see that their perseverance will be rewarded with mastery in the future, while the later take the absence of instant reward on first contact as evidence that the device is too complicated for them to use it. Designers, like us, are unlikely to be aware of such phenomenons and thus may not realize that, without a rewarding feedback coming very quickly even for first time players, the game will be rejected. Consequently, they must gather in-depth knowledge about the symptoms their patients exhibit to avoid population-specific issues such as these. We found that the quickest way to go about this information-gathering task was to consult with several expert caregivers, including but not limited to physicians, nurses, psychologists and medical assistants.

2. **Analyze the psychological and sociological context in which patients will play the game.** Even the most competent healthcare professionals are not necessarily much aware of what is going on in the life of their patients, who for example often form connections outside of the hospital through associations, reunions or simply support groups. Designers must thus explore this side too and try to interview patients and their relatives to learn about their daily difficulties and special needs. In any case, they must not limit their analysis to the

medical aspect and try to get a broader view on their target population. A good illustration from our case studies is patients' unfamiliarity with the kind of devices we use: elderly patients were far more afraid of video games and computers in general than we thought, while our test children were strongly attracted but surprisingly knew very little about the Wiimotes. It turns out that most of them were from very poor backgrounds and thus had little access to gaming consoles such as the Wii, even if many of them more or less knew what it was. Had we realized the true extent of this unfamiliarity, which in both cases is not a direct consequence of the medical conditions themselves, we most likely could have better predicted how accomplishing even the dullest of tasks with Wiimotes would feel so empowering for elderly patients and how motivating their mere presence would be for the children. We would consequently have made both gameplays much simpler right away without trying to motivate players with unnecessarily high richness and expressiveness. It is because we found this kind of mistake to be very common among other designers also that we recommend taking time to properly analyze the overall context, mostly in order to avoid spending costly human resources on the development of unnecessary features.

3. **Use an Action Research-based approach.** Points 1 and 2 are important, but the examples we used to illustrate them were negative on purpose. They were chosen to show that, even though we did follow the two aforementioned guidelines, we still made important mistakes in our design. In fact, both prototypes were conceived in close collaboration with competent, well-informed experts who were familiar with both the medical and socio-psychological sides of the population they were treating, and even them were proven wrong by subsequent testing. We think this makes a very strong case for using an Action Research-like method, especially for the focus on early, incremental testing, which was key in overcoming the issues of unnecessary and often detrimental complexity that we faced.

12.2 Patient Uniqueness

Even though they do build on medical and sociological knowledge to plan their interventions, music therapists often approach their patients in a way that is not very disease-specific, at least in the beginning of the treatment. That is because simply distinguishing between general conditions is rarely fine-grained enough to be useful in music therapy. Indeed, patients' reactions to music, which obviously greatly influence the therapeutic power of a given intervention, are so dependent on their personality and sonorous history that they are more or less always impossible to predict. In fact, music therapists have repeatedly tried to associate different types of music with various pathologies they could cure but never succeeded in doing so. Even to this day they are routinely surprised by the sometimes very counter-intuitive effects of music on patients.

Consequently, they are used to going beyond population-centric design into empirically adapting their interventions to the specific preferences of each patient they treat. Although a game necessarily has to be more restrictive in this regard than a classical music therapy treatment, we have found that it is crucial to give healthcare practitioners as much latitude as possible in adapting the gaming experience to each patient, most importantly from a sonorous point of view. To build such freedom for empirical personalization into a game, we recommend the following:

1. **Use a clearly defined framework, especially regarding interface devices, to place clear boundaries for customizability.** Interaction designers who work on big installations, usually at the frontier between video games and interactive art projects, often use the interface of choice as a starting point for their creation process. Indeed, for better or worse, designers will in most cases be inspired by a new device and try to see what they can make of it instead of finding an idea for a game and then figuring out which interface they could rely on. We acknowledge this and recommend that, prior to deciding on the gameplay, designers of music therapy games clearly specify the interface devices they will use. In doing so, they will gain the ability to impose well-defined boundaries to whatever adaptability they build into their games, which is crucial mostly to avoid wasting resources on planning for unnecessary extensibility. In our case, settling on using the Wiimote beforehand made it easy to tell healthcare practitioners what could conceivably be done or not in the game and thus saved a lot of time. Indeed, such non-experts in the HCI field, at least from what we saw, often have very high expectations about new devices that need to be dispelled. For example, we were able to quickly try and rule out Michel's first idea of an absolute location-based interaction for MAWii as well as Dr. Péquignot's suggestion of displaying a full octave with all twelve semi-tones of a virtual piano keyboard on screen, as both would have been totally impractical given the rather poor precision of the Wiimote's IR pointing mechanism. Had we not decided on the Wiimote beforehand, we may have tried to meet the expectations of our experts by supporting other devices, again introducing unnecessary complexity, since we have shown that simple Wiimotes work just fine if used properly.

2. **Be pragmatic and build on whatever works, since motivation seems to be inherently unpredictable.** It matters not whether

patients are motivated by what was intended to appeal to them or by something else; the only important thing is that they willingly play and enjoy the experience. Indeed, in both projects, skilled caregivers were able to make use of whatever source of motivation the patients had, even when it seemed misguided or even potentially harmful at first. In the case of MAWii, Michel experienced little difficulty turning the children's positive but potentially destructive excitement, induced by the presence of the Wiimotes, into highly desirable constructive motivation. As for MINWii, at least one patient appeared to be strongly motivated by the shooting challenge itself, disregarding the music more or less completely. Even though we at first thought that this would have bad consequences, especially when it triggered violent comments and recollections, in the end this patient always referred to the pistol in a positive, joking fashion and even convinced another patient to join in with his "cowboy" argument (see Section 10.2.2).

3. **Use highly parametric implementations to allow for easy fine-tuning.** It is most of the time very hard to predict which set of parameters will work best before trying many different values and combinations. Consequently, designers and developers must make sure that no strong assumptions of this kind are hard-wired into the design or the implementation, as it will otherwise block or at least greatly slow down the incremental design cycle prescribed by Action Research. Our scrupulous application of this rule allowed us to quickly reduce MAWii's sensitivity, which was far too high in the beginning, without losing much expressiveness, by playing with multiple parameters and fine-tuning the samples. Similarly, we were able to adjust the filtering algorithms for MINWii even in the middle of the sessions in order to obtain smooth movements of the pointer, which logically turned out to require a very different set of parameters for patients than for the healthy subjects who took part in the preliminary tests. Moreover, such flexibility also appeals to healthcare practitioners, who usually like to have as much control as possible over the behavior of the game, even though they end up working with the default options most of the time. This was especially apparent when Michel wanted to fine tune the pitches of even the drum and cymbal samples. The children probably did not notice the difference, but that does not mean that it did not matter, and it was in any case most likely worth the effort, as the better Michel felt with the game, the better he would use it.

4. **Make options switchable whenever possible.** Indeed, it is usually better, when changing a feature or adding a new one, to keep the possibility to turn it off or revert to the old behavior: even if the changes positively impact most players' gaming experience, there will almost

always be at least one to like it better the old-fashioned way. This was clearly illustrated by one elderly patient's love for the Improvisation Mode, which was completely unappealing to others but was kept for her, or the option to unlink the left and right hands to play with two instruments at the same time with MAWii, which was requested by some children for whom it was the logical way to go, but confused others so much that it was impossible for them to play like this.

12.3 Solo Vs. Group Therapy

Our final focus for this chapter is the debate between the advocates of solo and group sessions. One would think that solo sessions are more potent, since the therapist or caregiver devotes his or her full attention to a single patient, while group sessions are more efficient overall for society, since they let a single healthcare practitioner take care of several patients at a time. However this is not necessarily true. In particular, for specific issues such as our test children's very poor interpersonal and social skills, group therapy is likely to have a stronger impact as social contact with their peers is more challenging than contact with their therapist alone. Similarly, in solo sessions demented patients accomplished approximately as much in ten minutes as they did in one hour long group sessions with four patients, due to delays induced by frequent switching between players and occasional pauses to take care of one of the inactive participants. It follows that, in such a case, single sessions are more efficient from the point of view of the institution, since a single caregiver can treat at least one more patient per hour this way.

The previous remarks highlight the great importance of context in choosing between solo and group play. However, since neither of our games were built to be played autonomously by patients, we think that analyzing all of our work from a group-oriented point of view makes sense and indeed yields interesting conclusions:

1. **Leverage the fact that playing is "prescribed" and consequently always involves a group, with at least one patient and one prescribing caregiver.** Of course, such a group is highly asymmetrical, but it is a group nonetheless. First, this means that designers must always evaluate every feature of the game from both points of view, which requires extra work, but on the other hand can count on this group structure to provide motivation (see Section 14.2). Moreover, when dealing with highly disabled patients, as we did, the prescribing caregiver is almost always physically present for safety reasons. We took advantage of this and designed a part of the interface to be used exclusively by the person managing the gaming session. This enabled us to include many configuration options that would have had to be determined by default for autonomous play, as patients would have

been overwhelmed by so much choice. Finally, the presence of a dedicated caregiver makes it possible to use significantly more complex gameplays, which would be frustrating without help but can be very enticing with supervision, such as MINWii's Challenge Mode, which was fun and empowering but required the constant attention of a caregiver to avoid frustration because of failure, or MAWii's multiple instrument scheme, which would have been unthinkable without careful, slow introduction and supervision from Michel.

2. **Beware of the fact that designing a good multiplayer gameplay for cognitively or behaviorally challenged patients is very difficult.** This seems logical when one considers that players are unlikely to be able to engage in meaningful interaction if they can barely play alone. One is not to expect much close collaboration or even communication inside the game itself and should therefore probably not try to build a gameplay around multiplayer mechanisms. For example, in the case of MINWii, we could not find any accessible multiplayer gameplay that did not rely on improvisation, something which patients were completely unwilling to do, and consequently discontinued our effort in this direction. We were more successful with MAWii in this regard, as the children clearly engaged in meaningful sonorous interaction with the Wiimotes. However, even though we took the multiplayer dimension into account in our design, for example when we carefully chose sounds with very different characteristics so that they could easily be distinguished, we must note that the positive group processes that occurred were most likely primarily induced by Michel's careful management of the children. We can nevertheless say that MAWii was good enough to support these processes, which is what matters in the end (see Section 14.1).

3. **Focus on supporting social interaction between players, caregivers and families and friends.** Even though good multiplayer gameplay is very hard to achieve, even single player games are very good tools to foster social interaction. Since it is hard to imagine a situation where increased social contact could be detrimental, designers should analyze their gameplay through this lens and see how it can encourage players to interact with others. For example, the rather high difficulty of MINWii, at least from a demented patient's point of view, greatly promotes interaction with caregivers who must provide help and praise, so much so that one could almost consider it collaborative play. Similarly, the avatar creation process we want to include in MAWii would heavily rely on communication with the therapist, strengthening his or her bonds with the children on top of encouraging planning. But besides enhancing this asymmetrical re-

lationship with their caregivers and their families, games should also encourage patients to interact with other players. This was precisely the purpose of MAWii, which successfully supported sonorous communication between the children, but even MINWii proved efficient in this regard, in spite of its single player gameplay. Although it was not really expected, the players' experience indeed greatly benefited from the "I play, you sing" dynamics that emerged from the group sessions, spurring meaningful and surprisingly complex communication and collaboration between players.

Chapter 13

Action Research

Action Research is a paradigm-changing methodology that was introduced by social scientist Kurt Lewin in the 1950's for the analysis of social processes in groups, usually of moderate size. Instead of taking a purely observational stance and trying to have as little influence as possible on the people they study, its advocates adopt an interventionist approach: they try to have a transformative influence, of positive nature of course, and study the group as it changes. This has the advantage of allowing researchers to uncover mechanisms that would have remained invisible to pure observers, at the expense of the ability to gather quantitative, unbiased data since (1) it is hard to perform quantitative assessments on a rapidly changing population and (2) the data collected, and even more so its interpretation, are bound to be seriously biased if the researchers are an active part of the body they study.

Although we are not really studying our target populations in the way a social scientist would, our game design process can greatly benefit from such a methodology. Indeed, constantly analyzing patients' reactions to the software as we progressively refine the gameplay seems like a sound idea, as the various low-level processes that give rise to fun are very subtle and variable and thus hard to see without direct experimentation. Moreover, the fact that the data we may collect with this approach is likely to be flawed is not of much importance, as what interests us at first is to gather significant anecdotal evidence to guide the optimization of the gameplay. Thus, we hereafter give our recommendations on how to ensure that the design process incorporates what to us are the three essential assets of Action Research: incremental design, smooth introduction into the target context and positive outcome of the research process itself for the target population.

13.1 Incremental Design in Four Phases

One of the cornerstones of Action Research is the incremental approach: transformation is induced progressively by small steps, with constant collection of feedback from the actual target environment and integration of the subsequent refinements into the next iteration. This is a very classical approach in video game design, which, for the case of healthcare games, we suggest be implemented in four phases:

1. **Make an *a priori*, simple and robust prototype after thorough discussion with expert practitioners.** From our point of view, this is clearly the best way to get to the point where actual user tests can begin. One may think that the best course of action would be to make several different crude sketches of what the end product might be like, and compare patients' reactions to the various gameplay in a real clinical setting. Indeed, such an approach appears to be more scientific and less dogmatic, since it lets end users, and not the designers, decide what is best for themselves. However it would also be extremely time-consuming, and overall completely impractical, mostly because no matter how much work is put into these prototypes, they are more or less bound to all be seriously flawed. Indeed, as we already explained, even expert practitioners have much difficulty evaluating the impact of countless details of the game mechanics that can make or break a gameplay in spite of their apparent insignificance. Thus, we recommend the creation of a very crude prototype which, instead of being used to compare many different gameplay flavors, demonstrates only the absolute core mechanisms of the gameplay which would be common to any version of the game. Such an early and rudimentary yet testable version can usually be obtained quickly and be used to validate the main characteristics of the game and gather much needed first feedback that will give the expert practitioners involved a significantly better idea of how to conduct the main phase, which comes next.

2. **Perform a small-scale incremental evaluation for a significant period of time, with constant collection of feedback and a debriefing after each session to decide what to change, add or remove for the following test.** We suggest involving no more than ten users, as serious meta-analyses have shown that one testing session with this many subjects is sufficient to uncover 90% of the usability issues of a web interface [169]. In fact, Nielsen advocates for even smaller-scale but repeated studies, saying that three five-user tests at different times in the design process should be preferred to one fifteen-user trial. However, since we are not dealing with mere websites but with healthcare programs where safety and usability are

critical, we suggest taking extra precautions by involving more than five users. We thus settle on this limit of ten, which appears to offer an already good safety margin for an incremental protocol. Nevertheless, if funding is scarce, we too recommend cutting on the number of users instead of on the number of iterations, as the ability to validate new oritentations before investing too much time into them is crucial to keep development costs in check. This is exactly what happened with MINWii's Challenge Mode, which our early evaluations flagged as obviously too complicated and led us to focus on Reminiscence Mode, or MAWii's multi-instrument scheme, which was put aside for a while and reintroduced very progressively, after significant modification, once the children had accumulated enough experience with just one instrument.

3. **Test any modification whatsoever, even if it seems harmless or barely useful.** Indeed, the smallest changes sometimes have dramatic impact, good or bad. Since even experts often get it all wrong and prove unable to predict the consequences of the modifications they propose, thorough testing is very important, as it can not only prevent the inclusion of harmful features but also demonstrate the unexpectedly beneficial impact of others, saving designers a lot of time. For example, the simple addition of color stickers on the Wiimotes, which we thought would not have much impact on children, on the contrary completely stopped their complaints about being unable to distinguish themselves from the other players. Had we not tested this idea right away, without much hope but simply to gather information, we would have wasted our time on much deeper but completely unnecessary customization of the Wiimotes. On the other hand, the glissando option in MINWii, which to us was simply extending the gameplay and thus could not have any detrimental effect, failed because even our experts had misjudged the extent of patients' motor issues. Instead of enriching the gameplay, it prevented them from playing with pleasure, as it made them much more likely to produce parasitic, unwanted and thus confusing notes, something which we, with our much better coordination, failed to see when we tried this feature.

4. **Freeze the design once a mature gameplay has emerged, refactor the source code and start dissemination.** With production versions of both MAWii and MINWii well underway, this is where we are at with our two projects. We therefore cannot give much feedback on this step but nevertheless have two important comments to make. First, with weekly implementation of new features, modifications of gameplay, correction of bugs or even removal of unnecessary options during several months, the source code for the software is very likely to be quite messy and need a complete overhaul. If this step is omitted,

it will be very difficult to maintain and enhance, in particular preventing the all important cultural adaptations we recommend in Section 14.3. Moreover, this overhaul is, according to us, the most suitable moment to switch from prototyping hardware and software, chosen for power and flexibility, to their production counterparts, which are more likely to be chosen according to licensing and cost constraints and thus require significantly more work to be integrated. Once this is done, large-scale diffusion can start even if the application is still in an early development phase. Indeed, because fun and motivation are our primary concern, it remains ethical to advocate diffusion in the healthcare community even if thorough therapeutic evaluations with a fixed design have not yet been conducted. We thus advise designers to invest time in early dissemination because it greatly benefits everyone: patients and their caregivers will be eager to try accessible yet fun activities and will in return help future therapeutic assessment by providing feedback and financial support.

5. **Do not start therapeutic evaluation before fun is guaranteed.** We also have little to say about this step, since none of our projects has yet reached this phase, but there is one crucial point to consider, which plagues many poorly designed serious games: fun should be guaranteed, meaning that the game should remain a game, even if it undergoes modifications because of therapeutic or other "serious" concerns. That is why therapeutic evaluation should not come before the key characteristics that make the game fun are identified and understood well enough for designers to ensure that they will not be taken away. Otherwise, therapy-oriented modifications could rid the tool of its motivational power, which would ruin its actual therapeutic impact instead of increasing it.

13.2 Smooth Introduction in Therapeutic Settings

Healthcare practitioners are almost always short on time, while institutions are invariably short on staff and money. Moreover, as they become better informed, patients and their families are increasingly wary of medical interventions, with concerns for their safety and well-being that were mostly overlooked even just a decade ago. Because of all this, it is critically important for designers of new healthcare tools such as music therapy games to take all the necessary steps for a smooth introduction of their product in the clinical universe. Failing to do so will likely result in big deployment difficulties for the prototype systems, preventing designers to obtain the user evaluations and general feedback that are at the core of any Action Research methodology and are in any case necessary to gain the trust of the community.

To ensure such smooth integration, we recommend the following:

1. **Strongly involve at least one expert on the target pathology and treatment in the project.** Of course, more is better, especially if they are experts from different fields or functions, such as a physician and an animator, as we had for MINWii. In any case, for both projects, we heavily relied on our experts' knowledge and intuition. We were routinely surprised to see how different from ours their vision of the pathology and the requirements it implied in terms of gameplay was, despite our extensive preparatory study of both pathological impulsiveness and dementia. This was especially true of our expectations for the average skills of patients, which were instantly shattered to pieces by all of our experts: Michel explained that the seemingly rather chaotic recordings that he played for us, which we did not find musically pleasing at all, were the best he could obtain from the children and were in fact full of very positive signs. Similarly, Dr. Péquignot made it clear that any interaction for which the coordination of multiple joints was necessary was out of question, instantly ruling out everything that we had in mind prior to the interview. Furthermore, in addition to providing crucial knowledge without which we would inevitably have designed far too complex tools, the experts involved provided much sought-after test subjects and backed up the diffusion of the research in their community. Without their help we could not have gained the trust of other healthcare practitioners, who often have seen countless poorly designed new tools and have become suspicious towards ground-breaking innovation.

2. **Make sure that the system, even in its prototype version, is very robust and requires very little initial investment in time for basic use, from patients and from caregivers alike.** First, if a system takes too long to set up, fails too easily and must be restarted often or requires too much training, busy healthcare practitioners will disregard even the most promising prototype because they lack the time to try it out. Similarly, if the gameplay is too complicated for patients and forces caregivers to explain its workings over and over and assist players completely, both will get frustrated and eventually refuse to continue the experiments. These concerns with schedules were especially salient for Michel who demanded that MAWii be ready to use in less than three minutes, as he had very little time to set up after the person occupying the music therapy room before him left and could not afford to meddle with wires and configuration scripts once he had four impulsive children inside with him. Time constraints were not as pressing with MINWii, since specialized animation staff usually have slightly more time on their hands to set up complex activities for

residents, but our ensuring quick and easy installation proved useful nonetheless when we were denied access to the animation room several weeks in a row and each time had to find another place to set up while patients were waiting.

3. **Keep development and end-user costs very low.** Even though this seems like a no-brainer at first glance, we contend that it is in fact one of our most controversial recommendations. Indeed, it is to a large extent true that people will not count their money when it comes to their health. Therefore, medical products are often sold for very high prices that would be unacceptable in other fields, but here supposedly reflect the costly validation process that one must go through to have one's products deemed suitable for healthcare purposes. It would thus makes sense to more or less disregard costs and try to make the very best system we can, with custom hardware and software and numerous high-end features. However we chose to take the opposite approach and strive to keep costs very low by relying exclusively on off-the-shelf hardware and free software as well as avoiding the development and implementation of all unnecessary features. For example, the visually very simple yet soothing interfaces of both games avoid eye candy almost entirely, which has strong medical justifications because of the attentional disabilities of our two target populations but also dramatically cut development costs, as graphic managers are often the most time-consuming part of an application. Our decision to limit costs with such techniques was partly philanthropic, as our goal was to allow as many people as possible to benefit from our games, but it was mostly a matter of pragmatism: since many people remain skeptical of serious games and music therapy in spite of the growing body of evidence supporting their usefulness, it would simply have been impossible to find large funding for our projects. We thus had no choice but to be very careful financially. We think that we have shown that this obstacle is not insurmountable and can even be turned into an asset, and thus advise others facing the same kind of issues to adopt the same approach instead of searching for more money.

4. **Plan ahead to have the resources necessary to provide strong, long-term support to the healthcare practitioners on the team.** Again, all these professionals have very little time on their hands and, no matter how motivated they might be, their mere participation in the project is already likely to be a big sacrifice for them. Thus, designers and developers who wish to see their systems truly put to the test in a real clinical environment must be prepared to accomplish many support tasks that they would not expect to have to take care of in other contexts. This of course includes providing the hardware as well

as complete and responsive technical support but extends far beyond that to the most mundane tasks. For example, we had to bring all the hardware to the institutions every time for all the tests of both games, even though in the case of MAWii we were not even allowed to observe the sessions! We did this because our collaborators from the healthcare world, for safety, financial and schedule reasons, did not possess the necessary devices and were in fact not even allowed to store them in the institutions without filling countless paper forms and asking for multiple authorizations, which they neither had the time nor the energy to do. This task and many others of the same kind proved very time-consuming, which is why we strongly emphasize the need for designers and developers to plan for such interventions and save some time for unexpected work such as watching over four demented patients while their usual caregivers respond to an emergency.

13.3 Research as a Therapeutic Tool

The final key asset of Action Research in our context is its focus on ensuring a positive outcome of the research process itself for the target group, regardless of how successful the study is from an actual scientific point of view. This is extremely important for us, since we are having patients and caregivers participate in projects that take up a significant amount of their time with no financial compensation. Moreover, our games have no guaranteed positive therapeutic impact and, although careful design and early testing under the close supervision of expert caregivers make this very unlikely, could conceivably even have detrimental effects. Therefore, we see our trying to make the research process itself therapeutic as a fair compensation for patients' investment. However our motivation here is again only partly philanthropic, since this approach has great advantages for game-makers too and can even be the key to a successful design process. Thus, we recommend the following to try to make the research process therapeutic even if the risks and time consumption for patients and caregivers happen to be limited:

1. **Put patients in the center of the design process to enhance their self-esteem and their mood.** This is is the number one lever that is at game-makers' disposal to achieve a positive outcome for the design process regardless of the results. Indeed, patients often feel lonely and ostracized because of their illness and are frequently clinically depressed because of this. Consequently, making them feel acknowledged and even important by asking for their feedback and showing them that their suggestions were actually taken into account and implemented in the game is very positive for their mood. In our case, the children testing MAWii kept on asking questions about the

designers whom they had never seen and even uttered several heart-warming compliments that were a great source of motivation for us. In much the same way, demented patients kept thanking us for the way we cared for them. They kept commenting on how lonely they were and on how the research consequently was a great opportunity for much sought-after human interaction. Moreover, many were ecstatic when they discovered that we had added their favorite song to the system's repertoire at their request. All this in return made the experience very positive for everyone, us included, and we consequently advise anyone following our methodology to work the same way. Indeed, it is just a matter of communication and thus requires very little effort: since patient-centric design is a necessity anyway, following the present guideline is simply a question of making it clear for patients that they are the number one authority.

2. **Use the predictably positive outcome of the research process as an argument to overcome potential ethical barriers.** Indeed, ethical concerns are often very problematic when it comes to testing new systems such as ours. First, physicians are skeptical of such treatment methods and in general wary of new products. Therefore, they are frequently not very keen on granting the necessary authorizations for research that they see as a source of extra work or even as a potential legal hazard. Second, most of our test subjects, children and elderly patients alike, were not considered able to decide for themselves whether or not they should participate in our studies, and obtaining written consent from families was much more difficult than from the few patients who could sign for themselves. There is no doubt that our emphasizing the positive impact on patients' self-esteem that the research was more or less bound to have was instrumental in getting physicians and families to give us their authorization in spite of their reservations. Consequently, we think this argument should be put forward by all the game-makers in the same situation as ours.

3. **Use the resulting increase in patient and caregiver motivation to get a better end product.** As we repeatedly said, one of the great barriers to successful design and testing in a real clinical setting is the lack of close involvement of sufficiently many expert caregivers. Just like it makes it easier to obtain various authorizations, emphasizing the positive outcome of the design process for the test patients can be a great argument to motivate caregivers. First, most if not all of them find their work very demanding and would not continue if they did not take great pleasure and pride in doing whatever they can to help their patients. Second, anything that lifts the mood of those whom they are in charge of is bound to have an overall positive impact on

the efficiency of their unit, since happier patients are usually much easier to manage or even pleasurable to take care of. Consequently, we suggest that game-makers use these arguments to ask institutions for higher investment in their project in the form of longer testing with more patients as well as more in-depth feedback from caregivers, two things that are obviously more than likely to result in a better product.

Chapter 14

The Power of Simplicity

We have been making numerous references to this last chapter for a simple reason: in both case studies, it seems that most of the design flaws we detected, as well as a majority of the potential enhancements we imagined, ultimately boiled down to matters of simplicity, for caregivers, patients or even for the designers themselves.

In this chapter, we organize our guidelines for the design of simple systems along three axes, which more or less correspond to three different but related visions of simplicity. First, we insist on the implications of the fact that music therapy games are tools for caregivers and thus should be made as simple as possible so long as they reach their objectives. Second, we make the case for instant fun, which can only be achieved if the game is very simple to understand and use. Third and last, we give our recommendations on how to use culture-specific and patient-specific levers to increase fun, advocating simple and direct references to cultural and personal tastes as opposed to the creation of complex and original background contexts, storylines, characters and so on, to which designers tend to be attracted when they see the tremendous possibilities that devices such as the Wiimote offer.

14.1 Neither Instruments nor Normal Games, but Tools

Inventors and makers of music instruments usually aim for a given timbre, but also strive to achieve the highest expressiveness and versatility possible. Similarly, commercial games almost invariably advertise the supposedly never-before-seen freedom they offer to players in terms of movement, strategy, interaction with the game's universe or other players and so on. This is especially true of the increasingly popular sandbox-type games such as *Grand Theft Auto IV* [170] or *Minecraft* [171], which emphasize rich and complex game mechanics to encourage emergent gameplay, leading players to set their own goals, sometimes as unbelievably complex and unexpected as implementing an arithmetic logic unit[1] within the game.

On the contrary, with our games we do not intend to reach such complexity, as their point is simply to be used as tools by healthcare practitioners or caregivers. Thus, they just need to be complex enough to accomplish their task. Once the design fulfills its basic goals, designers are much better off striving towards simplicity and refraining to implement additional exciting but unnecessary features. Here is what we recommend for advancing in this direction, and why:

1. **Build the gameplay from the ground up in small increments and start trials with end users as soon as the first prototype boasts just enough fundamental features to be worth evaluating.** The justification for this is that unessential features are likely to disrupt the assessment of patients' reaction to the core game mechanics. Indeed, their presence will encourage caregivers to try different configurations, thus making it impossible to compare the results between the different trials, and, most importantly, will make the outcome of the experiments depend on too many parameters, preventing designers to get valid feedback on the core of the game in itself. We had this problem with MAWii, for which the first trial did not provide as much interesting information as it could have regarding the children's understanding of the sound choice mechanism: they were confused by the related yet very different instrument switching feature, which was far too complex to be used right away and should have been introduced much later. Fortunately, we avoided this issue with MINWii because we started testing much earlier, but we still could have had a prototype ready in much less time had we realized, for example, that having only one instrument available for a first test was sufficient.

2. **Focus on making the core interactions more accessible and intuitive rather than on refining or extending the gameplay with subtleties and additional features that will most likely rarely be put to use.** As we explained earlier in this thesis report, it is very difficult to put oneself in a patient's shoes, so difficult in fact that even the experts among our teams were often proven wrong when it came to evaluating patients' skills. Thus, the basic gameplay that is decided upon prior to testing is almost bound to be too complex and pose big usability issues. This for example was clear with our initial choice of a high sensitivity for MAWii: in addition to failing to increase expressiveness as we intended, because the children's skills were too poor to leverage such subtlety, it turned out to confuse them by greatly augmenting the number of notes triggered involuntarily. As

[1] The ALU, in a computer, is the basic circuit that performs the basic operations such as addition, negation, logical tests and so on.

for MINWii, in a certain sense the addition of the Challenge Mode proceeds of this search for accessibility and simplicity: although it is an additional feature, it responds to demented patients' need for guidance that prevented them from improvising and thus can be seen as the correction of a usability problem more than an actual extension of the gameplay. A better example of the later would be glissando, which, as discussed in Section 13.1, was indeed a complete failure.

3. **Choose technologies that are simply good enough and keep in mind that enough is often much less than expected.** Designers should indeed be better off relying on cheap, robust and widely available hardware than on high-end devices, as long as it has sufficient capabilities. First, testing will be cheaper and easier to organize since multiple prototypes can be constructed with little resources. Second, building the system and coding the software will probably be easier and yield a more robust product thanks to standardized tools and mature software libraries. Third, the final price and the effort required to build a system will be much lower for the end-users than if they have to buy complex or even custom hardware. Our case studies clearly support these three arguments. First, we have demonstrated that rather low-end tools such as the Wiimote were sufficient for our purposes. Second, we have been able to lead our two projects to completion with very limited funding, which would have been impossible had we had to buy custom devices and license expensive software technologies. Finally, we have obtained two systems that can be built for as little as $300 or even $100, for MAWii and MINWii respectively, as long as one already possesses a computer.

4. **Make the game fun, but not necessarily addictive like a commercial game.** Indeed, patients will only play under the supervision of a caregiver, probably for at most half an hour a day, since the games are designed in such a way that they cannot play on their own without external help. Furthermore, addiction can have adverse effects: children addicted to MAWii would be at risk of losing sight of the music therapy session they are participating in, while elderly patients may experience dangerous exhaustion from too lengthy playing sessions[2] and even get frustrated when they try to start the system and realize that they cannot play without the help of a caregiver. Thus, it seems more efficient to focus on usability and instant fun than on creating

[2] A patient who voluntarily participated in an informal demonstration session at Broca Hospital enjoyed playing and being praised so much that she kept at it for an extended period of time, probably making more of an effort than she had in a long while. After about 20 minutes she went into an epileptic seizure and then fainted, scaring us to death. We were glad to see her recover quickly afterwards, but decided to impose a 15-minute maximum length for sessions so as to avoid any other episode of this kind.

an unnecessarily rich game play encouraging patients to play hours on end.

14.2 Instant Fun

Speaking of the necessity of instant fun is a concise way of saying that a healthcare game, no matter what its purpose is, should rely on simple mechanics that instantly appeal to and reward first-time players. First, if the game is to be used as a healthcare tool, it is crucial that as few patients as possible reject it, which is why instant reward is necessary. Indeed, contrarily to drug-based treatments, which have a good chance of success even without patient consent, acceptance and adhesion to the treatment are *sine qua non* in our case, as one cannot unwillingly have fun. Second, as we said in the previous section, patients are not going to play the games for lengthy periods of time and will not have the possibility to train at will. Thus, they will not be able to enjoy the kind of very complex gameplay that only becomes rewarding after significant mastery has been achieved, even if they are willing to do so. Consequently, we hereafter give advice to ensure and increase the likelihood of healthcare games generating fun instantly:

1. **Avoid strong, explicit challenge and scoring, which are unnecessary in a supervised context and may deter unskilled patients.** Obviously, a prerequisite to making a game rewarding is that it does not punish players with unavoidable failure or a score that could emphasize their poor performance if compared to that of others. In commercial games, designers who want to create an instantly rewarding experience still have to make do with challenge and scoring, as they are usually necessary to motivate players in the long run. However here, since patients play under the impulsion and supervision of a caregiver, their motivation is extrinsinc[3] and such motivators thus appear less important. One may think that they could nevertheless remain necessary, but neither MAWii nor MINWii include strong, mandatory challenge or scoring, and both still proved greatly appealing to patients even in the long run. Thus, we advise designers to dismiss strong challenge and scoring altogether, as their beneficial effects nowhere nearly compensate the potentially dire influence they may have on the least skilled patients.

2. **Guarantee instant reward and, if possible, make it pleasurable not only for the target player but for the entire group.** There

[3]Extrinsinc motivation refers to motivation that comes from outside an individual, such as rewards, grades or, in our case, encouragements and praise from the supervisor of the gaming session. In their theory of self-determination, Deci and Ryan oppose it to intrinsinc motivation, which comes from inside the individual [172].

is always only one occasion to make a good first impression. Since patients presented with an unusual task often have a strong tendency to quit as soon as they find something on which to ground their refusal, in our case this first impression is crucial. First, for players to be rewarded instantly, the core mechanics involved must be extremely intuitive, so that first-timers can explore the game rationally instead of trying actions randomly. This is especially true for gesture-based systems: beginners could conceivably press all the buttons on the controller one by one to see what happens but cannot possibly be expected to try every single possible 3D gesture to discover the controls. Second, there must be an easy way to obtain a satisfying reward very quickly, even if further training reveals that this first outcome was in fact characteristic of a rather poorly executed action. Applying these two principles made it possible to immediately catch the children's attention with MAWii, as just randomly shaking the Wiimotes was already enough to produce a satisfying guitar sound, which was very important since their attentional deficits make them very likely to disregard anything that requires even the smallest bit of patience. This approach was also instrumental in getting skeptical or anxious demented patients to try the game in spite of their reluctance: the pistol made the interaction scheme obvious and they were thrilled to see that with it even they could instantly produce music pleasurable for them and everyone else in the room, just like the other, more adventurous participants who played before them did.

3. **Internalize extrinsinc motivation, which is only a starting point, as quickly as possible.** Having caregivers present to encourage patients to play alleviates the need for potentially detrimental challenge and scoring and provides a safety net for players whose motivation might falter, but healthcare games should still try to have patients internalize this extrinsinc motivation by supporting the self-attribution of goals. This means that the gameplay must, in spite of its simplicity, offer a fair amount of potential progress as well as long-term rewards that patients can understand and pursue. With MAWii, the all in all rather good expressiveness of the Wiimotes makes it possible to aim for a given sound, pattern or texture or even try to start a collaborative effort, as several groups of children did, sometimes even with spontaneous preparatory discussions. In MINWii, the goal patients set for themselves is usually to play a given song to completion to get praise from the caregivers and congratulations and thanks from other players. In any case, there should always be more to the game than instant reward, but, since finding such longer-term goals that will appeal to all of the patients is very difficult and potentially demoralizing for the least skilled players who might fail, we advise to keep

them implicit. Thus, the game should be rich enough to offer potential higher level rewards but rely on caregivers to set patient-specific goals and encourage or stop their pursuit when necessary.

14.3 Culture and Patient-Specific Products

The last lesson we draw from our two case studies is that, although things such as the gameplay, the hardware or the organization of the sessions are important, the single most powerful lever to design a successful music therapy game is the cultural dimension. We have settled on two interesting gameplays in our case studies, but our conviction is that we could have been just as successful with very different games, because the most important thing is not the game itself but what meaning patients imbue it with. It is thus absolutely critical to pay very close attention to this process, even though it is very hard to study or to influence in a predictable manner. Here are a few directions for making culture-specific and even patient-specific games to encourage and build upon meaning creation by patients:

1. **Use simple cultural common denominators: they are very powerful even though they appear cliché.** This point vividly illustrates the discrepancy between our vision of our games as designers and the kind of meaning that patients end up superimposing on their own play. We would usually want our applications to offer an original experience with innovative gameplay and intriguing sound and instruments that would give us access to sensations we cannot get in real life, such as playing a lightning fast rock solo with the gigantic bells of a cathedral. However patients clearly see our games as an opportunity to gain access to experiences that we as healthy subjects consider much more mundane, simply because they are always denied access to these basic pleasures due to their disabilities. This explains why, while we thought the children would love synthetic sounds such as the atmo and the robot, they turned out to be much more attracted to the guitar and the flute, or why elderly patients, instead of wanting to improvise or play virtuoso-level musical pieces with ethnic instruments, simply wished to use violin or piano sounds to play and sing the popular songs they loved. We think it is crucial to take this only superficially surprising difference of vision into account and thus encourage designers to emphasize simple, common experiences, which on top of being what patients really crave are usually much better shared interests across sometimes very heterogeneous populations.

2. **Rely on patient feedback, even if it appears biased or strange, because it always yields better results than following a designer's often mislead intuition.** It is very hard to guess what the

proper cultural levers to use are, and even more complex to predict what patients' personal tastes will be and how they will project them on the game. Consequently, we reckon that it is best to rely on the feedback they provide, even if it seems hard to exploit, and try out whatever they ask for in the game. Had we not listened to such feedback, we would never have included guitars or flutes in MAWii, since from our point of view manipulating these instruments with percussion-like gestures was counter-intuitive and thus likely to be confusing for the children. Similarly, had we failed to take into account elderly patients' comments showing that no matter how bad their pointing skills were, their only concern was their being able to remember the lyrics, we would never have tried the Reminiscence Mode, since we found such a gameplay far too dull to be attractive. Our own experience, with these two examples and many others alike, proves that the best results are usually achieved through patient-centric design, because our vision of the world is too different from that of the patients not to misguide us. We thus recommend that designers try to recognize their own opinions as the natural prejudices of a healthy person and put the patients' suggestions first, regardless of how strange they might seem before testing.

3. **Focus on evocative power: for patients, playing is primarily a projective experience, which makes it the single most important aspect of the game.** This seems obvious when one uses games for analytical therapy [72], but our case studies strongly suggest that this is also the case for any other kind of healthcare game. Patients appear to imbue their gaming experience with strong meaning, contrarily to many healthy players who are motivated only by challenge or experimentation and simply want to get the best score or experience something new. Our guess is that this tendency for projection is a consequence of their condition. Their disabilities constantly make them long to be just like anyone else and logically push them to consider games precisely as a means to achieve this, just like many GTA players, especially the younger ones, are thrilled to become a mighty yet cool gangster for a while. No matter where it comes from, this projective tendency is strong and should be met with sufficient evocative capabilities by incorporating whatever sounds, songs or even visual elements that carry strong meaning for the patients. That is what made MAWii so successful, as it let children tap into the very high social value of musicianship, which is best incarnated by the ubiquitous guitar. That is also what made MINWii's Reminiscence Mode so powerful, as it included many songs that were directly linked to patients' happy memories. We suggest that designers try to include as many such meaningful elements in their games and, more impor-

tantly, look for signs of such evocative power during testing, because they constitute very strong hints that the game is on the right track.

Chapter 15

Quick Reference Summary

Here is a quick reference summary of our 32 recommendations:

Population-Centric Design

1. **Make a thorough medical review of the different pathologies and disabilities commonly present in the target population.**

2. **Analyze the psychological and sociological context in which patients will play the game.**

3. **Use an Action Research-based approach.**

Patient Uniqueness

1. **Use a clearly defined framework, especially regarding interface devices, to place clear boundaries for customizability.**

2. **Be pragmatic and build on whatever works, since motivation seems to be inherently unpredictable.**

3. **Use highly parametric implementations to allow for easy fine-tuning.**

4. **Make options switchable whenever possible.**

Solo Vs. Group Therapy

1. **Leverage the fact that playing is "prescribed" and consequently always involves a group, with at least one patient and one prescribing caregiver.**

2. Beware of the fact that designing a good multiplayer gameplay for cognitively or behaviorally challenged patients is very difficult.

3. Focus on supporting social interaction between players, caregivers and families and friends.

Incremental Design in Four Phases

1. Make an *a priori*, simple and robust prototype after thorough discussion with expert practitioners.

2. Perform a small-scale incremental evaluation for a significant period of time, with constant collection of feedback and a debriefing after each session to decide what to change, add or remove for the following test.

3. Test any modification whatsoever, even if it seems harmless or barely useful.

4. Freeze the design once a mature gameplay has emerged, refactor the source code and start dissemination.

5. Do not start therapeutic evaluation before fun is guaranteed.

Smooth Introduction in Therapeutic Settings

1. Strongly involve at least one expert on the target pathology and treatment in the project.

2. Make sure that the system, even in its prototype version, is very robust and requires very little initial investment in time for basic use, from patients and from caregivers alike.

3. Keep development and end-user costs very low.

4. Plan ahead to have the resources necessary to provide strong, long-term support to the healthcare practitioners on the team.

Research as a Therapeutic Tool

1. Put patients in the center of the design process to enhance their self-esteem and their mood.

2. Use the predictably positive outcome of the research process as an argument to overcome potential ethical barriers.

3. Use the resulting increase in patient and caregiver motivation to get a better end product.

Neither Instruments nor Normal Games, but Tools

1. Build the gameplay from the ground up in small increments and start trials with end users as soon as the first prototype boasts just enough fundamental features to be worth evaluating.
2. Focus on making the core interactions more accessible and intuitive rather than on refining or extending the gameplay with subtleties and additional features that will most likely rarely be put to use.
3. Choose technologies that are simply good enough and keep in mind that enough is often much less than expected.
4. Make the game fun, but not necessarily addictive like a commercial game.

Instant Fun

1. Avoid strong, explicit challenge and scoring, which are unnecessary in a supervised context and may deter unskilled patients.
2. Guarantee instant reward and, if possible, make it pleasurable not only for the target player but for the entire group.
3. Internalize extrinsinc motivation, which is only a starting point, as quickly as possible.

Culture and Patient-Specific Products

1. Use simple cultural common denominators: they are very powerful even though they appear cliché.
2. Rely on patient feedback, even if it appears biased or strange, because it always yields better results than following a designer's often mislead intuition.
3. Focus on evocative power: for patients, playing is primarily a projective experience, which makes it the single most important aspect of the game.

Conclusion

In the course of this Ph.D., we introduced MAWii and MINWii, our own blends of music therapy and video games, into two actual clinical environments: a day-care hospital for children with behavioral disorders and the geriatrics unit of a medium-sized hospital. We did so in order to validate an emerging and exploratory therapeutic approach, provide feedback to orient future similar initiatives and, hopefully, have a positive impact on the well-being of patients and their caregivers. This research proved promising, interesting and even often entertaining, as patients surprised us with their unexpected reactions, skills and opinions. It also proved very fulfilling, when patients thanked us for making their treatment more enjoyable and caregivers praised our tools as truly useful, as shown in our two main publications regarding this thesis research [98], [135].

The previous chapters gave an in-depth look at each of the steps of the entire game creation process, focusing successively on the definition of a general design framework, its application, first with MAWii and then with MINWii, and finally on the lessons to draw from the comparison of the two studies. This conclusive part first summarizes the main contributions we made during these four phases before laying out the plans for future research, some of which is already underway. We then close with a discussion of the potential extension of our findings to other pathologies and contexts to give general orientations for the gamification of healthcare.

Contributions

The research methodology used in this thesis is somewhat unconventional: it relies on mostly anecdotal evidence, gathered during two different but related case studies, to give insights on a very exploratory if not entirely new topic, musical healthcare game design. Thus, our conclusions are largely qualitative and, as such, are primarily intended to serve as rough guides for future initiatives, not as unchallengeable, precisely quantified claims that can readily be transfered to other fields without careful critical review.

However, we had no choice but to settle for such a methodology, as qualitative design and usability studies such as those that we conducted are an absolute prerequisite to guarantee patient safety and obtain subsequent funding for large-scale therapeutic evaluations. Moreover, because we acknowledged the necessarily limited generalizability of whatever results we would get in such a context from the very beginning, we chose an Action Research methodology, which we think let us make the best of the limited resources we had.

To justify this last claim, we review our three main contributions, in the order that we listed them in the introduction: first, our detailed analysis of the needs and constraints that any designer of a musical healthcare game must take into account; second, our two games and their impact on patients; last, our 32 guidelines for future initiatives.

Needs and Constraints

We turned the needs and constraints that emerged from our review of the literature and our multiple interviews with various healthcare practitioners into a set of research objectives summarizing the main issues that we think any musical healthcare game must address:

- Games can and must act as treatment catalysts, meaning that they must increase players' motivation for their treatment to enhance its impact. Without a strong motivational effect, the large amount of time and effort that their conception requires would most likely be better spent on something else.

- Ease of use, in all its dimensions, is absolutely crucial to get both healthcare practitioners and their patients to try and use new systems. The main concerns here are easy setup using little hardware, low financial and training costs for caregivers and adaptability to each patient in terms of accessibility and personal musical tastes.

- Data collection and analysis tools are highly desirable to ground music therapy in evidence-based practices and provide physicians with tools to assist and speed up diagnosis, screening and monitoring processes.

Note that actual therapeutic impact in itself is not an absolute need and is thus not listed here, although it is of course desirable. Indeed, we think that any game that fulfills the criteria listed above will be successful: patients and caregivers are always in need of adapted distractions, of which very few exist as patients' well-being has routinely been grossly overlooked until the last decade or so.

Production-grade Games

MAWii and MINWii were conceived according to the principles of the design framework we devised, primarily in order to validate the adequacy of said framework with the criteria we had established for the success of a musical healthcare game. However we think that the contributions of these two case studies extend much further. Here is a brief overview:

- The promising results of our tests validate the methodology we established in our framework. They show that using specialized video games in a real clinical setting with impulsive children or demented patients is indeed feasible and likely has strong therapeutic potential.

- When we studied MAWii, not even Michel expected the children to be so attracted to mainstream instruments. We showed that our intuition that the children would crave the synthetic or heavily distorted sounds that we tend to associate with the Wiimotes, though shared by most of the experts we consulted with, was completely mislead as the most popular instrument, by far, was the guitar. We consider this to be a very significant finding that largely spurred our subsequent recommendations about relying on the evocative power of direct, well-shared cultural references.

- With MINWii, what surprised us the most was the extraordinary success of the Reminiscence Mode. Again, our intuition as video games designers was completely wrong. Patients were highly enthusiastic and even sometimes exhibited astonishing cognitive abilities in response to this gameplay which we, as healthy users, thought would be far too dull to be interesting, let alone highly stimulating. Again, we see this as an important finding which will help designers to make better-adapted games in the future by focusing on evocative power instead of challenging gameplay.

- By choosing an Action Research methodology, we were able to enhance the well-being of our test subjects through the research process itself. Moreover, we took advantage of our two case studies, which we knew would not produce statistically significant quantitative results anyway, to incrementally design two prototypes that became mature enough to be turned into actual production-grade applications by Benoît Pin, a software engineer from our lab. MINWii V1.0 is now downloadable for free on its dedicated website[1], and MAWii V1.0 is in the making.

We did give up quantitative results altogether by choosing an incremental methodology which, by changing the software every week, made it impossible to reliably assess the evolution of patients' skills. However, we traded this ability to produce quantitative data for two games that, because they have been progressively enhanced through such an incremental, patient-centric design process, can and hopefully will be put to use by practitioners all over

[1] See www.minwii.org.

the world, thanks to the new fully free production-grade versions that are or will be available soon. Consequently, we think that our research will have a much greater impact than if we had simply conducted quantitative but necessarily small-scale studies with crude prototypes, especially since large-scale, quantitative therapeutic evaluations are likely to take place in the near future anyway.

Useful Guidelines

By comparing our findings from the two case studies, in particular regarding issues shared by patients suffering from impulsiveness and dementia, such as attentional or learning deficits, or even common to virtually all patients, such as an increased need for social contact due to feelings of loneliness or a will to be "normal" for a while, we inferred 32 guidelines that should ease and speed up the development of better music therapy games or even healthcare games in general.

Our recommendations are organized along three main axes:

- Healthcare games are tools for caregivers and practitioners. As such, they only need to be good enough to serve their intended function. This means that designers should simply use good enough technologies and design good enough gameplays to appeal to patients and keep them interested for the 30 minutes or so at most that they will play daily. All the technological and gameplay refinements that make the richness of a commercial game are here superfluous because there are no hardcore gamers to appeal to.

- Instant fun is to be preferred to strong challenge or intricate gameplay. Indeed, patients are always supervised and encouraged by caregivers when they play the game. Thus, thanks to this extrinsinc motivation, they do not need to be motivated by explicit scoring or long-term goals, which are consequently better left out to avoid deterring less skilled patients. What they do like however is for the games to be intuitive and instantly rewarding, because it makes them feel empowered.

- Evocative power and cultural factors are key to making a game appealing. We think that any game mechanics that make patients' very projective play possible will work, provided that this projection is supported by powerful, widespread cultural references that help patients imagine themselves as healthy, successfull "normal" people, contrarily to commercial games which usually aim for innovative and unusual experiences.

These various recommendations will guide the future enhancement of our applications to maximize therapeutic impact without loosing the essence of what makes them good games and good tools. They will also hopefully help other designers working on musical games for other pathologies or even completely different types of healthcare games.

Perspectives

Future developments of our research can take two broad orientations. First, we can extend our work, which up to now has been primarily geared towards the creation of fun occupational tools, to assess the actual therapeutic impact of such tools. This will be the first focus of this section. Second, we can broaden the scope of our conclusions by validating our results with other pathologies and populations, or even with completely different, non-musical healthcare games. The discussion of such a transformation of our conclusions from recommendations for the design of a musical healthcare game into guidelines for the gamification of the healthcare world will end this thesis report.

Therapeutic Validation

Due to various events beyond our control[2], the process leading to the therapeutic evaluation of MINWii is significantly more advanced than that of MAWii. However, both will be put to this new kind of test, albeit in very different ways. If they are successful, these therapeutic studies will be among the first to give statistically solid quantitative results on the potency of active music therapy in the treatment of behavioral disorders and dementia and, hopefully, be instrumental in finally establishing it into the position of major secondary or even primary treatment we think it deserves.

The production-grade version of MINWii is already available for download on its dedicated website [173] and will soon begin to be used autonomously, i.e. without our presence, at Saint-Maurice Hospital once the robustness of the new version is confirmed. This will provide us with very interesting long-term feedback on the potential benefits of MINWii for the general functioning of the geriatrics unit as a whole.

Moreover, thanks to the very positive results of the preliminary usability study we conducted at Broca hospital with a fixed version, we are confident that our pending (small) funding requests for another experiment will be successful. This would let us begin three separate randomized controlled experiments, each involving approximately 40 patients, to assess the effects of MINWii on parameters such as stress and anxiety, as measured by saliva cortisol levels, depression, as measured by the Cornell scale, and overall well being, as measured by the QoL-AD. We believe that these studies will demonstrate the therapeutic value of MINWii and allow us to diffuse it not

[2]The day-care center where we conducted our first case study was closed due to budget cuts.

only as an occupational tool, but also as an actual treatment if used in the right conditions.

As for MAWii, once the production-grade version is ready, we would like to experiment with the personalization process. Again working in close collaboration with Michel, we intend to design a mechanism for children to create their avatar instrument. They will give it a name and a face, choose or even record its sounds themselves and equip it with accessories such as audio effects.

Thanks to the very promising results of our preliminary study, we hope to obtain the funding and authorizations to conduct a year-long, controlled study with a group of about 30 children to compare traditional sonorous communication to the same protocol augmented with the avatar personalization feature described above. Positive results would mean that MAWii actually enhances the therapeutic power of Michel's method, instead of merely providing an alternative to traditional instruments, even though that alone already has multiple benefits.

Role in the Gamification of Healthcare

While we do not intend to mindlessly generalize results that we recognize to be safely applicable only in our very specific context, at least until further research confirms their transferability to other pathologies, populations and types of healthcare games, we think that our conclusions can serve as useful guides for the design of the many gamified applications that will inevitably hit the healthcare market in the coming years. Such recommendations will be especially crucial to make the connection between the two very different worlds of healthcare applications and video games, as designers coming from one of these two fields will want or likely be forced by economic concerns to venture into the other. We hope that work such as ours will prevent those coming from the healthcare world from calling games things that are merely slightly more entertaining treatments or applications, as well as help game designers get a feel of the effort they need to make in terms of accessibility compared to commercial games or even classical serious games in order to adapt to disabled patients.

There is no doubt that this paradigmatic evolution will be supported by great progress in terms of hardware and software power. That is why we insisted on the fact that neither the Wiimote nor MAWii and MINWii were the panacea of musical healthcare gaming. They are simply examples of what can be achieved with a proper methodology using rather low-tech hardware and small funding. In the future, many new, more powerful interfaces, the first of which will likely be tactile displays, will become as cheap and easy to use as the Wiimotes, and there is no doubt that healthcare games will reap the benefits of these evolutions. We hope that our work on optimizing the process of introduction of a new type of interface, in our case motion sensing, in a real clinical setting by focusing on cheap and robust off-the-shelf devices will make it easier and quicker for designers to put future new technologies in the hands of healthcare practitioners and their patients.

Moreover, the pervasiveness of all these new technologies is rising very fast: while home treatment devices that enable long-distance interventions such as examination by a specialist for rare cases or perform permanent monitoring of certain parameters such as blood pressure are becoming increasingly popular, we are most likely only witnessing the very beginning of this trend. We think that musical healthcare games will play a major role in this process, thanks to their motivational power and the always astonishing ability of music to form bonds between seemingly completely different people. The conjunction of (1) increasingly powerful data mining algorithms helping physicians with diagnosis, screening, monitoring, treatment customization etc. and (2) gamified medical tests and treatments for patients that will seamlessly collect this data in a fun and easy way, for example thanks to music, will undoubtedly revolutionize healthcare, replacing sporadic, painful visits to a specialist with constant yet fun monitoring and personalized "push" instead of "pull" interventions from physicians.

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