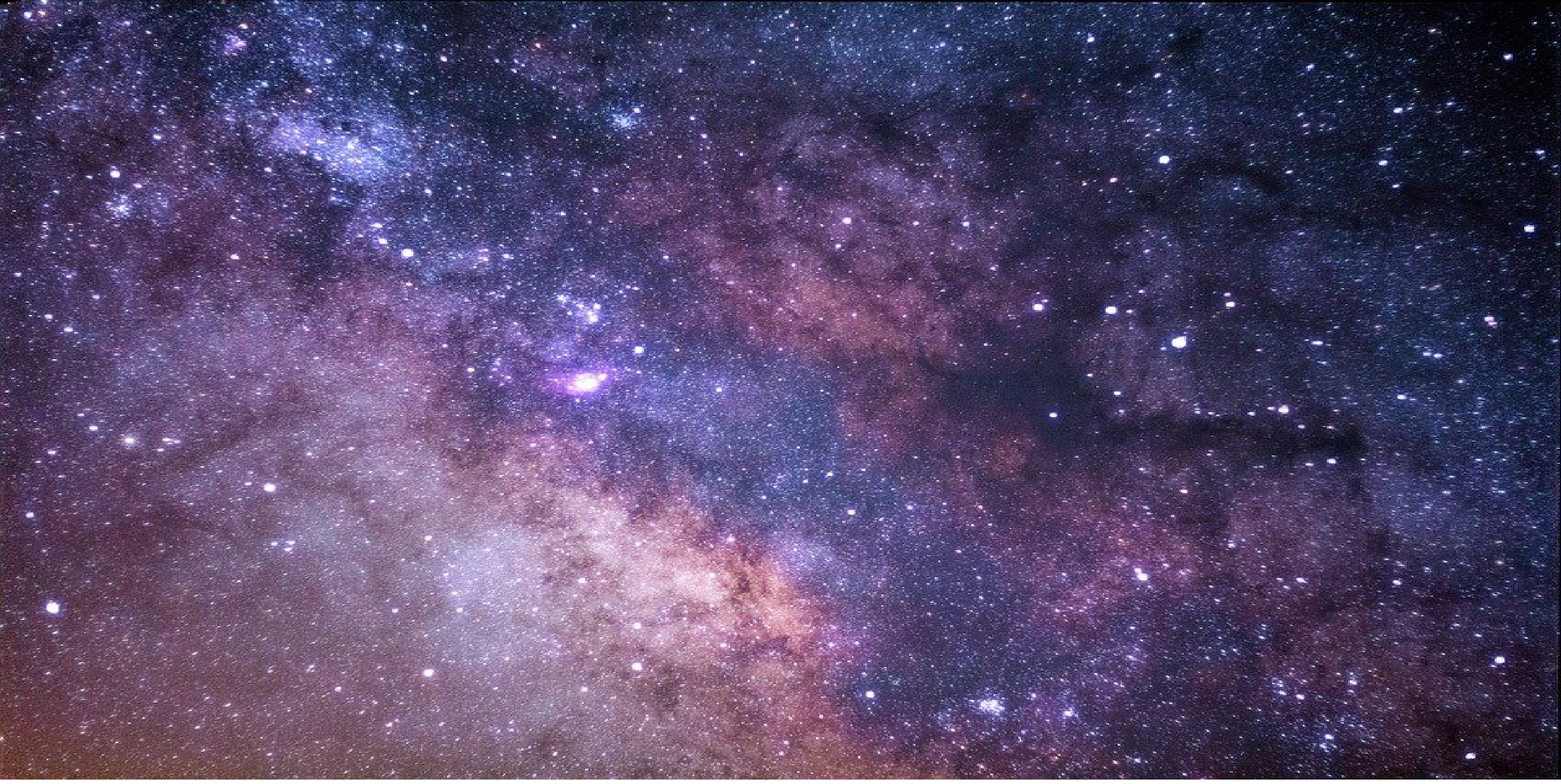

Possibilities for Somabased Design and Serious Games Towards Balance Rehabilitation Technologies

The Case for Creating Somaesthetic Experiences

Sophus Bénée Olsen

Sound and Music Computing, G1001, 2021-05

Master Thesis

STUDENT REPORT

AALBORG UNIVERSITY

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Abstract:

The call and interest towards technologies promoting physical activity has seen an increase in recent years. The current thesis investigates how to connect movement-based interaction, somaesthetics and serious games, to develop a technological intervention that can be used to increase motivation for doing balance rehabilitation exercises. Designing through a 1st-person perspective, a prototype using sound as the primary stimuli has been developed. The prototype revolves around distributing weight across a Wii Balance Board, where the inputs lead through a processing chain resulting in an aural feedback designed to promote somaesthetic experiences for the user. Through spatial audio techniques, the aural feedback is additionally used by the user to navigate and explore an invisible virtual world. A small user study with 4 patients at a rehabilitation clinic was conducted to investigate if the proposed prototype could be used for motivation in a balance rehabilitation context. Results are promising, demonstrating as a proof of concept that a somaesthetics inspired technology can be used to promote motivation for patients to continue and maintain their balance exercises.

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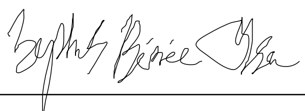
Preface

Aalborg University, May 10, 2021



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Chapter 1

Introduction

Recent years has seen a vast increase and general interest in the design and development of technologies to assist in the field of physical rehabilitation [7, 12, 22, 26, 31, 36]. Physical rehabilitation (PR), as a general term, describe the programs, processes and activities involved in the gradual recovery of patients suffering from a variety of motor-inhibiting difficulties. To highlight the scope of PR interventions, it has been used in recovery processes from motor-inhibiting illnesses such as *chronic pulmonary dysfunction, heart disease, stroke, sclerosis (both multiple and lateral), Parkinson's disease, brain injury, spinal cord injury, amputation, arthritis, burns and chronic pain* (and more) [34]. The vast scope that PR covers results in a similarly large design space for technology related solutions. The growing body of literature reveals that technologies within the PR context largely falls within two categories, namely technologies that does not require supervision and can be used at home [10, 22, 30], and technologies which are meant to be used in a clinical setting under the supervision of a therapist [4, 12]. The current thesis will limit the scope to focus on supervised audio-visual technology solutions to assist the therapist in their daily routines. The goals of such developed technologies can largely be categorised as, **1)** improving the quality of a PR exercise or program, thus increasing the rehabilitative outcome, **2)** attempt to increase patient(s) motivation for doing and completing an exercise, **3)** create solutions that enable patients to do an exercise without the immediate need to have a therapist present to guide them. Most studies within the first category narrow their focus towards one specific motor-inhibiting illness while the second and third attempt to make more general solutions that work within several PR programs or exercises. Within the general solution category, a repeating trend is activities and exercises focusing on postural stability, also known as balance [34]. Balance exercises is a general aspect within almost any PR program, and generally seen as a precursor for further rehabilitation progress in other areas [12]. Balance exercises within PR can largely be categorized as containing the following [23, 34]:

- Postural orientation exercises: the act of training the body's spatial orientation movements, namely active control of body alignment with respect to gravity.
- General muscle building, especially neck, back and upper-limb musculature.
- Coordination exercises, for example the relationship between visual stimuli and an internal frame of reference.

These types of exercises most be repeated often to impact the rehabilitative outcome [34]. Hence, in long term PR programs, patients have been seen to lose interest over time, becoming gradually more demotivated [10]. The term *exergames* (popularized by commercial products such as the Nintendo Wii and Microsoft Kinect), a derivation of the more general field *serious games*, has been used about technologies attempting to incorporate gamification elements (point systems, level advancements, game progression etc.) into existing exercise activities in order to promote motivation for continuing and extending physical activity periods [4, 26, 36]. While serious- and exergames generally covers gamification of any physical exercise, a targeted framework for using serious games within PR has recently been proposed [39, 40]. Another branch within human-computer interaction (HCI) that seems readily applicable in the design of PR technologies and subsequent serious games is *embodied interaction* (EI). In short, EI investigates how people explore and interact with technology spaces that move away from the standardized mouse and keyboard interaction [49]. Within EI, a specific school of thought referred to as *somaesthetic appreciation design* has been adopted in the design process of technology artefacts [6, 29]. One of the main ideas within somaesthetic design is to create applications that makes users reflect and think about the inner workings of their body (soma), i.e. direct their attention inwards [19, 24]. It is theorized that there exists a strong link between the auditory modality and movement-related sensory inputs [37]. Unsurprisingly, many soma-based designs rely on sound, rhythm and music as their primary stimuli and/or feedback of the developed artefacts [6, 29]. While these artefacts are largely meant to make their users reflect on, and consciously *feel*, their body, the ideas can be generalized towards PR technologies for balance as well [1]. Balance, in essence, relies on the three sensory systems; vision, somatosensory and vestibular [34]. When one of these systems is absent or otherwise inhibited, the central nervous system weights information from the remaining systems higher. Clinical studies on the effects that sound and music has on balance, has shown that a measurable improvement in various balance-metrics can be achieved through an aural stimulus [13, 15, 16, 27, 35, 47, 50]. The rest of this thesis will investigate how to connect the somaesthetic approach, serious games and PR to propose a prototype that uses sound as the primary stimuli and feedback mechanism to help and motivate rehabilitation patients in their balance exercises.

Chapter 2

Analysis

2.1 Considerations in Somabased Design

2.1.1 Somastaethics

The term *somastaethics* can be defined as the *"...critical, meliorative study of the experience and use of one's body as a locus of sensory-aesthetic appreciation (aisthesis) and creative self-fashioning"* [45, p. 302]. It is in essence a philosophical standpoint that challenges the way the body, *the soma*, has been viewed throughout the ages. Shusterman, in his original paper [45], argues that the body should be appreciated and accredited for more than being just a "replaceable, malleable" piece of meat that can be fashioned at will. The philosophy argues that our conscious will at times inhibit desired actions due to ingrained somatic habits overriding it. That is, we (people) are conditioned to perceive our bodies as a tool more than an "entity" in itself that should be delegated specific care and attention. Shusterman further define somaesthetics as having three distinct dimensions, *analytic, pragmatic and practical*. For the sake of brevity, only the pragmatic dimension will be elaborated here:

- **Pragmatic somaesthetics** emphasizes the various thoughts and methodologies behind shaping and remaking the body. This dimension can be considered to lie on scale anchored by "representational" and "experiential" somaesthetics. The representational part emphasize external appearance, while the experiential focus on the "inner", the felt bodily experiences that make awareness of somatic experiences more acute.

Somaesthetics as a discipline has later been integrated into the HCI community, especially the sub field of embodied interaction. The pragmatic nature of Shusterman's somaesthetics fits well into a scientific community where common research practises revolves around *participatory design* and *research through design* methodologies [9, 42, 51]. Authors such as Höök et al. [19, 20] has further integrated somaesthetics by combining the discipline as described by Shusterman and existing user-centered interaction design practices, thus adding more rigidity to the existing philosophical framework and creating more nuanced design methodologies applicable to the development of technological artefacts. Thought processes similar to that of Shusterman and Höök et al. can be inferred from authors such as Loke & Robertson [24] proposing a methodology towards movement-based interaction design. In the following, i will attempt to couple the most essential ideas presented by Shusterman, Höök et al. and Loke & Robertson into a concise formulation of a unified design strategy. The section concludes with design exemplars that relate these ideas towards balance rehabilitation technologies.

2.1.2 Perspectives in Movement- and Somabased Design

Of particular interest in these methodologies is the concept of *perspectives*. A perspective in this context is an approach towards a specific design process.

Somabased Design Perspectives

Höök et al. [19] distiguishes between three perspective modes, 1st-person, 2nd-person and 3rd-person. The 3rd-person perspective conceptualizes an observatory approach to design, encompassing routine methods in interaction design such as observing, interviewing and testing on users. Höök et al. puts forth the case of designing from a 1st-person perspective instead. The 1-st person approach is represented by the designer actively engaging his or her physical body with the artefact under consideration during every part of the design process. In other words, this perspective revolves around *being* the user, and attempting to experience what they will inevitably experience. Participatory design approaches is not neglected in this scenario. Höök et al. simply argues that in order to make a meaningful design artefact, the designer has to take active part in the participation aspect, not merely rely on observations. This, in the end, is theorized to create a stronger coupling between the intended design idea (mental map) and how it is perceived by its end users.

Movement-based Interaction Design Perspectives

The concept of perspectives is similarly adopted in [24]. While the ideas presented in [24] largely focus on *movement-based interaction*, their methodology and philosophical considerations bears close resemblance to those of [19] and [45]. Loke & Robertson [24] distinguishes between the mover, observer and machine perspective. The mover perspective reflects the concepts of the 1st-person perspective described in [19]. The mover perspective ensures that designers generate first-hand experiences about the activity being developed. As such, it serves the same purpose as in [19], namely that designers are more closely linked to the felt, lived experience of the potential user. The observer in [24]'s formulation does not revolve around general user testing. Instead, the observer represents the idea of movement-evaluation through inspection of data, for example video analysis or motion capture. The observer perspective is a loop meant to improve desired movement through performance and subsequent inspection. Finally, [24] bridges the gap into the world of computation by emphasizing the machine. Any application that uses movement as the primary source of interaction has to process and make sense of the inputs. Hence, this perspective is about mapping movement captured or recorded by some sensing technologies into meaningful representations and/or feedback for the observer and mover. It is important to emphasize that these three perspectives are not mutually exclusive, but rather meant to be explored together in a holistic fashion. Of course, more weight can be delegated one or the other. Moreover, the mover and observer are interchangeable, that is, the user can be the mover in some instances, while acting as an observer in others. Of course depending on the application at hand, the observer might even be a third party evaluating the mover.

2.1.3 Somaesthetic Appreciation & Making Strange

A key aspect of the design approach outlined in [24] is the concept of "Making Strange". The concept intends to change certain aspects of a familiar activity (in a conceptual sense). The idea is that these changes causes a necessary reflection to occur, which in turn removes automated behaviour acquired through habitual practise or experience. This notion ties exceptionally well together with Shusterman's [45] philosophical thoughts about ingrained somatic habits. The "making strange" conceptual idea can be used as a tool to break these habits, and as a result, enable reflection on the inner processes occurring within our bodies. The "Somaesthetic Appreciation Concept" (SAC) proposed by Höök et al. [20] conceptually falls within Shusterman's experiential pragmatic somaesthetics. The concept, similarly to "Making Strange", seeks to nudge people towards reflection and awareness of felt bodily experiences. A brief description of the characteristics encompassed by SAC can be outlined as; *subtle guidance* (directing attention, for example towards a part of the body, without stealing attention), *making space* (slowing down time, disrupting habitual routines and literal secluded areas), *intimate correspondence* (synchronized feedback loops) and *articulate experience* (provide opportunities to articulate the felt bodily experience).

2.1.4 Movement- and Somabased Technologies for Balance

Let us investigate how the aforementioned methodological approaches can be used within the context of designing technologies for balance and rehabilitation by investigating related design exemplars.

SWAY Prototype

The first example is SWAY [1]. SWAY is a conceptual space comprised of a mechanical plate containing a set of marbles. Through visual, aural and haptic feedback, SWAY provides information about micromovements in the postural stability of its user. Movement is detected by a Kinect, and shifts in posture controls the plate making the marbles move. Haptic feedback through vibrations is provided by a forceplate at the users feet. The idea is that the three modalities create playful experiences and encourages exploration of postural stance and stability. SWAY embraces many of the SAC characteristics. Its innate physicality relates it to *making space*. The quality of *subtle guidance* towards posture is achieved through the soundscape arising from the rolling marbles and the haptic vibrations. SWAY especially seek to embrace the quality of *intimate correspondence*, with the feedback serving as an amplifying mirror of the bodily micromovements.

SNAP-SNAP T-Shirt

The second example is the SNAP-SNAP T-Shirt [29]. SNAP-SNAP is a wearable garment embedded with a matrix of magnets spread out at even intervals across the back. Through rich haptic feedback, SNAP-SNAP gives information about the posture of the back. Intended for people suffering from repetitive strain injury, SNAP-SNAP seeks to create acute awareness of posture through playful and somaesthetic experience. The design process of SNAP-SNAP is a great exemplar of utilizing the different perspectives as laid out by [19, 24]. Working primarily from a 1st-person perspective, the designer molds the intentions of the garment to fit the perceptions of the co-designer. The co-designer, in turn, provides feedback on their reflections and felt experiences during a 3-stage design process. In addition, it serves a good example of the mover-observer perspectives. Switching between the designer being the mover, then becoming the observer during trials by the co-designer and vice-versa. The result of this design process is that SNAP-SNAP became an excellent example both in terms of using the *subtle guidance* and *intimate correspondence* SAC qualities. The strength of the haptic feedback was gradually corrected over the course of the design process, to provide just enough attention towards current posture of the back. The close coupling between muscle contraction/movement in the back and the haptic vibrations unifies in a feedback loop. The final design of SNAP-SNAP can be linked to the "Making Strange" principle as well. The final placements of the magnets within the garment require its user to move in uncustomary ways to activate the haptic feedback around certain parts of the back. This, in effect, was observed to cause the wearer to move more.

2.1.5 Implications for Balance Rehabilitation Technologies

Given the outline of the design strategy and a couple of design exemplars, let us now take a closer look on how this can relate towards physical rehabilitation (PR) technologies. Consider first the following analogy by Shusterman [45, p. 303]:

> *"... think of the struggling golfer who tries to keep his head down and his eyes on the ball and who is completely convinced that he is doing so, even though he in fact miserably fails to. His conscious will is unsuccessful because deeply ingrained somatic habits override it; and he does not even notice this failure because his habitual sense perception is so inadequate and distorted that it feels as if the action intended is indeed performed as willed"*

Similar to the golfer, a balance rehabilitation exercise consists of finely nuanced coordination between cognitive effort and bodily function [23, 30, 34]. To be effective in terms of rehabilitative outcome, these exercises have to be done as close to correct as possible [30, 34]. If we follow the analogy laid out by Shusterman, one can assume that a similar phenomenon of ingrained somatic habits might inhibit a rehabilitation patient in progressing past a desired threshold of rehabilitative outcome. This feeling of stagnation and lack of progress (whether it being conscious or unconscious) is theorized to lead to down-spiraling self-efficacy towards the activity and less motivation for continuing [10, 25, 34, 43]. Somaesthetics and somaesthetic appreciation is the act and process of gradually breaking down these barriers in the effort of re-creating oneself. Here, i emphasize process, as the somaesthetic school of thought and its subsequent utility is something you acquire and learn over time. The methodological foundation laid out by [19, 20] serves as a great strategy for helping rehabilitation patients past subjective barriers. The 1st-person perspective seems almost essential, to ensure a desired design idea matches a desired rehabilitation process.

Loke & Robertson's [24] mover-observer-machine perspectives serve to bridge another gap towards using the proposed strategy within PR. General PR programs revolve around patients performing an exercise which is subsequently evaluated by a therapist [4, 30, 34]. By designing with this in mind, the mover can be interpreted as the patient, while the observer is the therapists.

Towards Balance Rehabilitation Technologies for Motivation

It is important to emphasize that the two design exemplars (SWAY and SNAP-SNAP) described earlier is not designed within a PR context. To the authors knowledge, none, or at least very little, research has been done that takes a somabased design approach to PR technologies. These exemplars should merely serve as a vague stepping stone for inspiration of somabased design towards a technology specifically designed to work in a balance PR context.

A goal set out in the introduction was to investigate the possibilities for increasing motivation in patients towards continuing and maintaining their balance exercises. While little research has been done for this topic within the context of somaesthetics, it has been widely investigated elsewhere. One of these areas is the field of *serious games*. While one could argue that the practice of somaesthetics in itself might be enough to increase motivation, one has to keep in mind the repetitive nature of PR exercises [4]. Hence, to finalize a conceptual strategy for the design of a technological artefact based in somaesthetics, the following section will elaborate on approaches towards increasing motivation through serious games.

2.2 Serious Games

2.2.1 Serious Games for Rehabilitation

A serious game is generally seen as a "computer" game with a purpose other than pure entertainment. It has recently seen success in the general field of PR, and has been shown to help increase motivation in doing and maintaining exercises [4, 39]. Serious games does not have to be played on a computer with a classical keyboard and mouse, as described in the review by [40] who emphasize the utility of natural user interfaces (NUI). Great examples of a NUI could be a Microsoft Kinect or a Nintendo Wii. The review by Rego et al. [39] highlights a set of important considerations when designing serious games for rehabilitation:

- Rules: Every game is based on rules that provide structure during gameplay.
- Goals: The gameplay is goal-oriented, which should act as motivation.
- Feedback: Patients should be informed about training progress.
- Adaptability: The degree to which the difficulty can adjusted.
- Portability: The capability of the system to be used in many settings. For example at home.

Within the area of balance rehabilitation, the use of commercial NUI's such as the Microsoft Kinect and Nintendo Wii has garnered much interest. One study suggested that the games developed by Nintendo for the Wii Fit Balance Board has the potential to increase the quality of balance rehabilitation exercises [14, 46], while other studies has even suggested that he Wii Balance Board is an appropriate tool for measuring postural stability in clinical settings [28]. Unsurprisingly, other authors has incorporated the use of the Wii Balance Board into their own serious game projects [4, 10]. Below we will review one of these projects which relate to balance rehabilitation.

The RehaLabyrinth

The RehaLabyrinth by Baranyi et al. [4] is a serious game developed towards balance rehabilitation for patients who has suffered a stroke. The application is 2D and has been developed i JavaScript. Using a Wii Balance Board, patients have to navigate a ball around a maze while trying to collect points. The application has been designed such that a therapist can make custom mazes suited to individual patients. The app can be used from home, and patients therapy statistics are committed to an online database which can be accessed by the affiliated therapist. Patients can track their progress locally through the application.

Chapter 3

Design & Implementation

3.1 Initial Inquiries

The current thesis project has been realised in collaboration with a rehabilitation center in Copenhagen, Denmark. While taking a somabased approach to the design process is favorable for the eventual prototype development, one cannot neglect conventional consumer research approaches [8]. Hence, a small informal preliminary investigation was carried out at the outset of the project.

3.1.1 Preliminary Interviews

During two visits at the rehabilitation center, semi-formal unstructured interviews with the primary contact therapists was carried out. Results from these interviews are concurrent with the literature (e.g. [4]) and can be outlined as follows:

- General opinion from both therapists and associated management showed primary interest in technology that could be used without supervision.
- The intervention (i.e. the purpose of the technology) should not focus on improving exercise quality (i.e. measurable clinical improvement).
- General consensus among therapists was that the intervention should promote the participation factor for their patients.
- General interest in technology which patients could also use at home.

Target Group Investigation

These interviews also served to determine the target group of the eventual design. Sessions at the rehab center in this context consists of a mixed group of people of varying ages. Unique sessions for treatment of certain illnesses are available.

However, the therapists would use a classification of their patient teams as those being "bad" and those being "good". The bad teams are simply patients who are severely physically indisposed. The good teams are those who are almost functioning normally, and recovering from minor inhibitions. Independent of unique illness, age, and severity of physical inhibition, therapists would reuse certain exercise programs and schemes.

3.1.2 Preliminary Observations

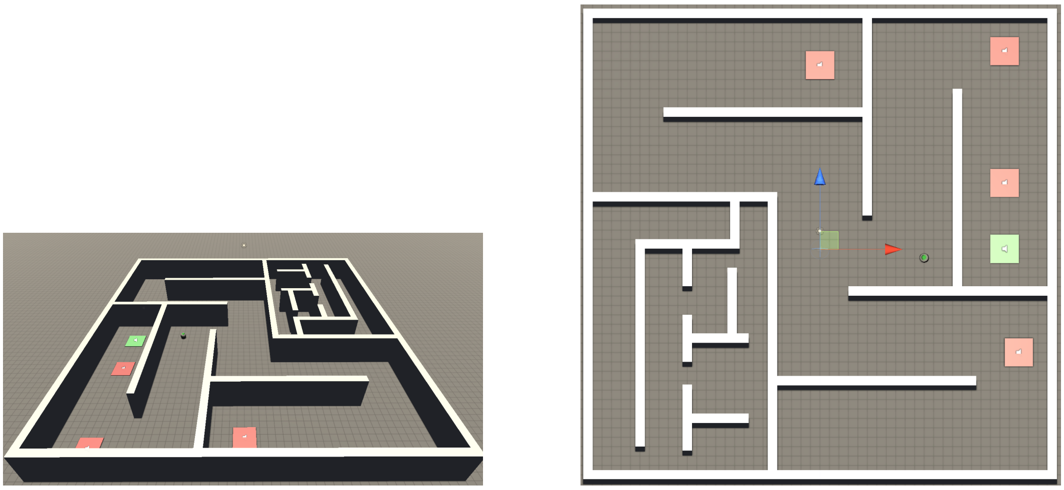
In addition to interviews, ethnographic observations were carried out over three PR sessions at the rehab center. These observations served two purposes: **1)** gather further insight on the potential target group and, **2)** generate an understanding of everyday sessions to determine which type of technological intervention best fit into daily routines. The results from these can be outlined as follows:

- A session team would usually consist of a single therapist and 4-6 patients.
- A session lasts on average about one hour. Time is scheduled into a brief warm-up followed by varying exercises. Individual exercises lasted on average between 5-10 minutes.
- Between 5-10 different exercises would be laid out, which patients would rotate through during a full session.
- Therapists would take a proactive improvisational approach in their sessions, using a variety of exercise tools if necessary for the patients.
- Time dedicated to individual patients by the therapist(s) is very limited. During some sessions, a single patient would require most of the therapists attention, leaving the rest to their own devices (albeit following a schedule laid out by program creators)

In Situ Interviews

During these observations, informal interviews were also carried out with both the present therapist and her patients. When asked whether the therapist could see herself using a technological artefact during her sessions, she was generally positive. She expressed that such a thing could be weaved into her program, or in some cases replace another exercise. However, she pointed out that if the technology was too difficult to handle (e.g. to complicated to understand or too unpractical to maneuver) she would be hesitant to use it.

A couple of the patients were asked reflect on their exercises. One patient explained, that his view towards an exercise was dependent on the challenge it presented. He explained that it was a self-reinforcing effect, whether he enjoyed it not. If the exercise was too difficult or too exhausting, he would gradually come to dislike it. A group of patients explained that it was largely dependent on their mood the given day, and what they perceived themselves to be able to do physically.



(a) (b)

Figure 3.1: An overview of the virtual environment (which is invisible to the users) developed in Unity.

3.2 Prototype Realisation

3.2.1 Software Stack and Computer Setup

The complete software architecture can be seen on fig. 3.2. The primary software running the prototype is a macOS program developed in Unity3D using the C# programming language. The program development has been realised through extensive object oriented programming (OOP) principles, and has been constructed in a modular fashion. The complete architecture can be divided into five distinct areas (as seen on fig. 3.2):

1. **Audio Module**: The audio module taps into Unity's built-in audio pipeline. It contains the main classes that handles all audio processing.

2. **OSCulator application**: An OSCulator application is responsible for communicating with a Wii Balance Board through a connected Bluetooth port. Sensor data from the board is parsed and further broadcast through open sound control (OSC).

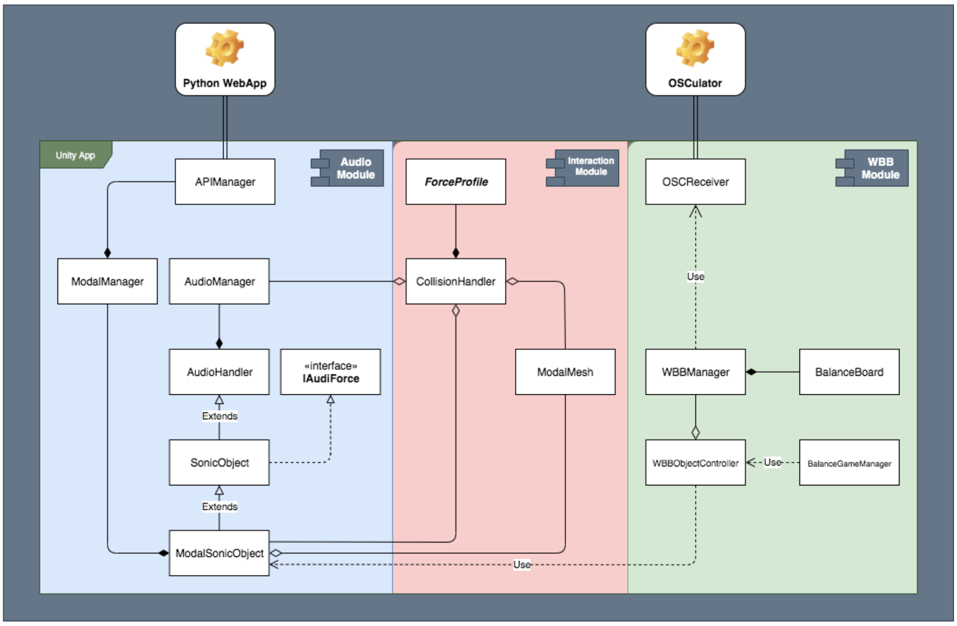


Figure 3.2: Full software architecture. Class diagram displaying the static relationships between classes.

3. **Balance Board Module**: The WBB module is in charge of receiving the OSC messages from OSCulator, and interpreting sensor data from the board. It also contains the main classes handling physics and game logic.

4. **Interaction Module**: The interaction module is the bridge between the WBB module and the audio module. It interprets user actions from the WBB module, and supplies excitation signals to the audio module.

5. **Python Web App**: The Python web app is a simple WebAPI that is in charge of heavy duty matrix operations.

3.2.2 The Intended Experience: An Overview

Consider the following highlevel overview of how the prototype is intended to work. A rehabilitation patient steps unto the Wii Balance Board, puts on a pair of headphones, and closes his eyes. By distributing weight across its four sensors, the **WBB module** controls a 3D object in a virtual environment invisible to the user (e.g. fig. 3.1). A physics simulation in turn makes the object move, and its kinematic properties are used to generate excitation signals which is used by the **audio module** to generate feedback to the patient. The rest of this section will explain the design process, design decisions, and certain implementation details more in depth.

3.2.3 The Mover

The current prototype aims to create an experience that encourages rehabilitation patients to explore and challenge aspects of their balance. To create a technological intervention that would fit into existing routines, the design began by deciding what kind of movement the experience should revolve around. By taking the perspective of the mover, different balance exercises were experimented with to get an idea about what kind of experiences patients presently had. Acknowledging that quality (clinical outcome) was not the primary focus, the type of movement could be something which patients nor therapists were not necessarily used to (which relates back to the "Making Strange" principle). A bodystorming session (see e.g. [44]) was used to generate and explore potential movements. During this session, conventional techniques used in balance therapy was tried, with interleaved improvisational movement patterns. In the end, the following basis for movement was decided:

> *The movement builds around challenging reactive postural control. With feet placed at shoulder length, the mover should perform conscious, slow perturbations of the upper body across his base of support, with the intention of pushing his center of mass to the limit of stability. Interspersed within these perturbations, are moments of brief standstill.*

The movement builds on top of existing balance exercises, such as postural orientation training, which revolves around active control of body alignment. Moreover, it has elements of general core muscle building. However, the movement is primarily intended to evoke the feeling of "Making Strange"; doing something we are not used to. Pushing the center of mass towards the limits of stability is what usually result in a fall. Because this is something we habitually (and unconsciously) tend to avoid, a tendency to overcompensate for safety means we usually do not explore the areas which lie just within the limit of stability. The moments of brief standstill is also slight reference to conventional balance exercise primarily revolving around postural sway and control. By having them interspersed within the movement, however, there might arise a situation were you have to remain still during a "fall".

3.2.4 The Machine

For the sensing technology, it was decided that Nintendo's Wii Balance Board (WBB) would be suitable. As described earlier, it has been used previously with some success. The WBB has some qualities which makes it an adept choice of use within the target PR context. These qualities can be outlined as:

- The WBB is distinctly ergonomic. Moreover, it is both smaller and weighs less than existing tools in the therapists toolkit. Consequently, it is an easy fit into daily routines.

- Due to its commercial nature, the WBB has been thoroughly tested, and is robust both in terms of its sensors and physical attributes. Hence, the therapists and patients does not have to worry about breaking anything during usage.
- The WBB measures weight distribution across its sensors with relative precision and low latency. As such, it provides the patient with a close coupling between movement and subsequent feedback.

The WBB is also a fitting device to enable the movements discussed previously. The physical device provides a concrete base of support with clear indication of feet placement (which, consequently, are approximately at shoulder length). Interactions with the board occurs through distributing weight across its four pressure sensors, hence also supporting the intended movement strategy of conscious perturbations across the base.

Processing Movement Input

Taking the perspective of the machine, mapping strategies on how to process the inputs to the WBB was investigated. The WBB communicates to its host applications through Bluetooth protocol. The current prototype uses the OSCulator application as an intermediary endpoint to parse the raw bytecodes broadcast from the WBB. OSCulator has built-in support for interpreting, calibrating and smoothing input received from the WBB. The parsed inputs are further broadcast from OSCulator through the open sound control protocol (OSC), which an external application can listen for.

Mapping Movement Input

The primary data of interest received from the WBB are the voltage readings from its four pressure sensors [17]. The mapping strategy from sensor value to user

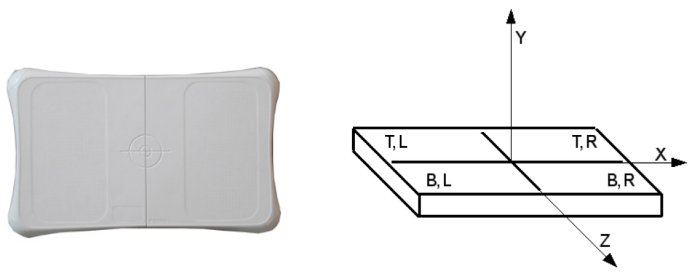
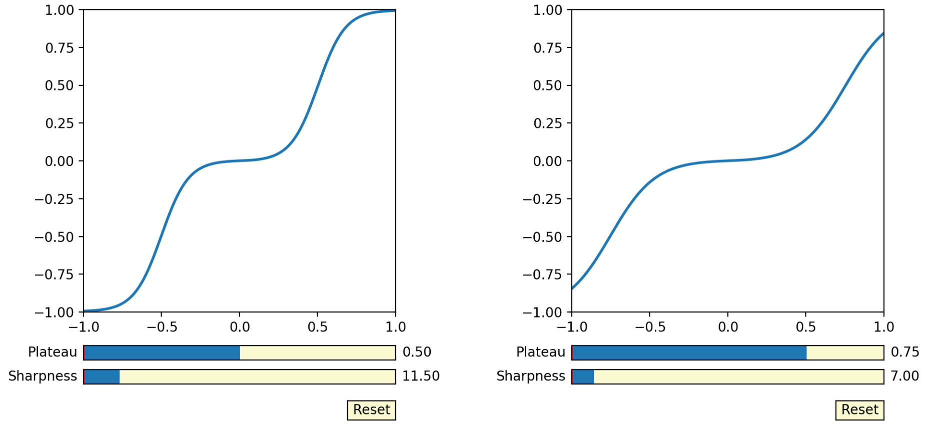


Figure 3.3: Wii Balance Board (left), and its local coordinate system (right). Image from [18].



(a) **(b)**

Figure 3.4: Different configurations of the calibration parameters, "sharpness" (c) and "plateau" (d).

feedback is inspired largely by the work of Hilsendeger et al. [18]. A physically correct computation of the weight efforts by the user is of less interest. Instead, the mapping serves to deliver values corresponding to the intended actions necessary to communicate the movement strategy previously described. We can interpret the force readings on each pressure sensor as the amount of weight (pressure force from the patient) necessary to rotate the board about its local X- and Z-axes (see e.g. fig. 3.3). Through a comparison scheme, we can compute two pseudo-angles as functions of time (here denoted $\alpha(t)$ and $\beta(t)$) by considering the current readings across all four sensors at time t (as seen in [18, p. 4]):

$$\alpha(t) = \frac{(F_{tr}(t) + F_{br}(t)) - (F_{tl}(t) + F_{bl}(t))}{\sum F(t)} \tag{3.1}$$

$$\beta(t) = \frac{(F_{br}(t) + F_{bl}(t)) - (F_{tr}(t) + F_{tl}(t))}{\sum F(t)} \tag{3.2}$$

Where $F_{tr}, F_{tl}, F_{br}, F_{bl}$ are the top-right, top-left, bottom-right and bottom-left sensor value the board delivers for each corner, respectively (as seen on fig. 3.3). The functions $\alpha(t)$ and $\beta(t)$ represents the pseudo-rotation around the X- and Z-axes, respectively. Both functions have a range in the interval [-1:1]. Due to calibration factors (which we have purposefully neglected during the development of this prototype), reaching the limits of the interval (i.e. max pressure around an axis) is very hard. To compensate for this, and provide a way to pseudo-calibrate, we used a concatenation of two logistic functions (e.g. [18, p. 5]):

$$\sigma(x) = \begin{cases} \dfrac{1}{1+e^{-c(x-d)}} - \dfrac{1}{1+e^{cd}} & \text{if } x \geq 0 \\ -\dfrac{1}{1+e^{-c(-x-d)}} + \dfrac{1}{1+e^{cd}} & \text{otherwise} \end{cases} \tag{3.3}$$

Where c and d are calibration parameters for adjusting the slope of $\sigma(x)$. The parameters c and d have since been denoted "sharpness" and "plateau", respectively (e.g. fig. 3.4). The sharpness parameter refers to how fast the input to eq. 3.3 (e.g. the pseudo-angles) reaches maximum value. In other terms, this configuration is used to control how much effort a patient has to produce in order to reach the maximum force limit. The plateau parameter is used to produce a stable area wherein the input goes to zero. This reflects a configuration towards how hard or easy it should be to acquire "standstill" (again, not physically).

Physics Simulation

Behind the scenes (invisible to the user of the prototype), a physics simulation is run within a virtual environment (e.g. see fig. 3.1). This simulation controls a virtual 3D-object, which is in turn controlled by the input from the WBB. Using the aforementioned mapping strategy, eq. 3.3 is used to compute a 3-dimensional vector, $\vec{f} = \{\sigma(\alpha), 0, \sigma(\beta)\}$ (with α and β from eqs. 3.1, 3.2 respectively) representing a steering force acting on the virtual object in the XZ-plane. The vector, $\vec{f}$, is clamped so that its magnitude always lies in the interval [0:1]. The mapping from the movement on the WBB to the software running the simulation, is analogous to a conventional joystick. Most of the physics computation is delegated to Unity's built-in physics system. However, an additional two parameters for configuration has been introduced; *maximum speed* and *maximum acceleration* which in turn enable further fine-tuning of the simulations behaviour. The kinematics of the virtual object are used to control a sound-engine, which provides the primary source of feedback to the patient. The sound-engine and its implications are described in more detail later.

3.2.5 A Brief Acknowledgement to The Observer

The mapping strategy revolves around a set of configurable parameters, which during the development of the current prototype was explored heuristically by taking the perspective of the observer. A small Python GUI application was developed to explore the relationships between movement on the WBB and the proposed mapping strategy (see an excerpt from this application on fig. 3.4). While these configurations could be delegated to the therapist in the future (through an integrated GUI system), they are currently left as presets. The application was utilized to discover an appropriate set of configurations which best matched the intended movement (as described in "The Mover").

3.2.6 Towards Somaesthethic Appreciation

The design of the prototype so far can be brought together by describing how the different aspects relate to creating somaesthethic experiences. Let us break down how the different elements of the experience correspond to certain qualities of SAC as described by Höök et al. [20]:

- ***Making Space*** has been approached by a couple of design elements. The experience (i.e. the prototype) is meant to be done with eyes closed. This should, in theory, force the sensory system to weight the vestibular and somatosensory systems higher (e.g. [34]). By placing oneself on the WBB combined with the closing of eyes, transfers your mind and body into a dedicated *space*, both mentally and physically. The interspersed moments of standstill slows down time, and provides an opportunity for reflection.
- ***Intimate Correspondence*** has been approached through the feedback loops arising due to the mapping strategy. This is connected to the aural feedback (to be explained) which is controlled by an invisible object controlled by physics. Properties of physics such as inertia extends the movement of the virtual object when attempting to do standstill, which in turn extends the aural feedback. This evokes a correctional movement in the mover, which results in a feedback loop until total standstill is achieved.
- ***Subtle Guidance*** is achieved through the design of the aural feedback, which will be explained more in depth.

3.2.7 Subtle Guidance Through Aural Feedback

The approach towards the audio design was to support the envisioned movement described in "The Mover". The audio is a result of a feedback chain starting from the mover, moving through the machine, and effects a physics system controlling a virtual object. Hence, there is an argument for making the audio be physically inspired as well. Recall the SWAY project (e.g. [1]), which created a rich soundscape through marbles rolling on a wooden platform. Drawing on this inspiration, investigations on the audio design was aimed towards real-time synthesis of rolling and bouncing objects.

Modal Synthesis

Originally a field to analyse structures in mechanical engineering (modal analysis) [3], the concept of *modal synthesis* has made its way into the field of audio engineering [2]. Modal synthesis can be used to model the aural properties of arbitrary physical objects to produce realistic sounds, for example that of surface friction, scratching and rolling. Within the computer graphics community, approaches to model 3D objects and extract their aural properties has seen much work, and optimized processing algorithms has enabled real-time synthesis possible [33, 38, 41]. Due to its feasibility in rendering realistic sounding rolling and bouncing sounds, a modal synthesis approach was adopted for the audio design. The implementation followed the approach outlined in Doel & Pai [48]. Doel & Pai describes an approach that takes its point of departure from an existing modal model;

> M, utilizing N modes at K different locations on an object as $M = \{\mathbf{f}, \mathbf{d}, \mathbf{A}\}$, where $\mathbf{f}$ is a vector of of length N whose components are the modal frequencies in Hertz, $\mathbf{d}$ is a vector of length N whose components are the decay rates in Hertz, and $\mathbf{A}$ is an $N \times K$ matrix, whose entries a_{nk} are the gain coefficients for each mode (excerpt taken from [48, p. 1]).

The modal model is used to construct a bank of N resonators, each with a resonant frequency of $\mathbf{f}_i$, $i \in 0, 1, 2, ..., N-1$. The individual resonators are modeled as a second order recursion filter (2nd order IIR-Filter) with the direct form:

$$y[t] = 2R\cos\theta y[t-1] - R^2 \sin\theta y[t-2] + x[t] \tag{3.4}$$

where,

$$x[t] = aR\sin\theta F[t] \tag{3.5}$$

with $R = e^{\frac{-d}{S_R}}$, $\theta = \frac{\omega}{S_R}$ and $F[t]$ an excitation signal. d is the decay rate in Hertz, ω is the modal frequency in Hertz, S_R the audio pipelines samplerate and a represents a gain for a mode at a given location. The modal model, M, was extracted using the algorithm proposed in [38] (which we will not describe here). The bank of resonant filters was directly implemented in native C# using Unity's built-in audio rendering pipeline.

Interacting With The Audio System

To interact with the modal synthesis engine, the bank of resonant filters has to receive an excitation signal. We model two different excitation signals, one for impact sounds and one for friction sound. The impact signal is derived from a pseudo-physical approximation as described in [48, p. 5]:

$$F[t] = F_{max}(1 - \cos(\frac{2\pi t}{T})) \tag{3.6}$$

for $0 \leq t \leq T$, with T the total duration of the signal in seconds, and F_{max} the magnitude of the impact. An excitation signal is sent to the **audio module** when the virtual object encounters a collision. Duration of the impact (T) is set as linear function of the relative impact velocity between object and the collision surface, with values between 20ms and 50ms. Impact magnitude, F_{max}, is set as the magnitude of of the impact velocity. Friction signals are generated by looping through an audio sample. The pitch of the audio sample is controlled by the current velocity of the virtual object. The audio sample used, was a recording made with a Zoom-recorder of a small wooden ball rolling on a jagged wooden surface.

3.2.8 Supplementing With Game Elements

A small set of game elements was incorporated into the prototype, giving the the patients some goals to search for while exploring their balance. A number of platforms were scattered around the virtual world. Some of these platforms serves as "obstacle", which should be avoided. Getting close to an obstacle, a small gravitational pull will push the virtual object, hence the patient, towards the center of the platform. If the patient does not manage escape the plate by applying force on WBB in the opposite direction, the whole program simulation will restart. Among the obstacles, a single target platform is present. The goal for the patient is to locate this target. When found, the patient has to keep the virtual object close to the center of the platform, until it disappears, and he gains a "point". After the target disappears, it will spawn randomly at a new location within the world.

To enable patients to locate these objects, they were equipped with an audio loop which was spatialized. The obstacles would emit a gloomy ambient loop, while the target would emit a happy, melodic loop.

Chapter 4

Evaluation

4.1 Initial User Test

To evaluate the prototype, a small study was conducted to investigate the question set forth in the Introduction, namely; *whether a technological intervention using a somaesthetic design approach to a serious game could be used to motivate patients in their balance exercises*. To answer this question, we measure a single psychometric variable, namely ***perceived intrinsic motivation***. Even though we are measuring distinct variables, the current evaluation should be considered *formative*, as it also serves as general usability test and user experience evaluation. Hence, in addition to the psychometric variables, the evaluation will attempt to measure perceived somaesthetic experience achieved with the prototype. These aspects and their implications should inform a possible re-design. A third purpose of this initial evaluation, is to determine how well the prototype could fit into a therapists routine.

4.1.1 Demographics

The participants consisted of four patients (*mean age = 71, SD = 8*), 3 being male and one female. In terms of the classification described in section 3.1, these patients were considered on the "bad" team, i.e. physically indisposed. Of the four patients, 3 were recovering from chemotherapy and one was having general balance issues. 3 of of the patients had never used technology in a rehabilitation context, while one had used it 4-5 times.

4.1.2 Test Methods & Materials

Perceived intrinsic motivation is measured using the relevant subscale (*Interest-Enjoyment*) from the Intrinsic Motivation Inventory (IMI) [21]. It is theorized that scores to the *Perceived Choice* and *Perceived Competence* scales serve as positive predictors towards intrinsic motivation [21]. Thus, we also measure those variables to

Figure 4.1: Test setup at the rehabilitation center.

correlate against the motivation score. As suggested in [21], individual scale items were rephrased to fit within the evaluation context. Additionally, since the test was conducted with Danish patients, all scale items were translated to danish.

To measure perceived somaesthetic experience, a 12 item Likert-type scale was developed by the author. Some of the questions for these scale items were borrowed from or inspired by tangential projects (e.g. [5, 18]), while some were developed by the author (see appendix A). The author has not attempted to validate the properties of this scale, and acknowledges a potential bias. Additionally, to gather further insight on the felt bodily experiences, the author encouraged participants to "think aloud" (as per the think-aloud method, e.g. [32], or by the "articulate experience", e.g. [20]). Probing questions in situ would also be availed.

Test Equipment

- 1 Wii Balance Board.
- 1 pair of headphones.
- a MacBook Pro 2014 running the prototype.

4.1.3 Test Procedure

The test was conducted 14/04/2021 at the rehabilitation center in Copenhagen, Denmark, during an actual therapy session. The prototype was allowed to take the place of an exercise, and be incorporated in a routine therapy session. Every participant read, understood and signed a content form allowing the author to use their data. The whole evaluation procedure took approximately one hour. Each participant was delegated 15 minutes, whereas approximately 10 minutes was used trying the prototype and 5 minutes to filling in the rating scales. Before trying the prototype, each participant was informed about the general purpose of the test (to evaluate general perceptions towards the proposed exercise scheme). They were asked to equip the headphones and step onto the balance board. Because this was the "bad" team, and to avoid the potential for injury, the board was placed behind a chair which the participant could use for support (e.g. fig. 4.1). From this point, the application would be run, and the participant was told to close his or her eyes and just explore the space available by distributing weight across the balance board. During this time, they were encouraged to report on their general thoughts. After a while, or if the tester recognised that the participant was stuck, they were allowed to open their eyes and try the application with visual feedback from the otherwise "invisible" virtual environment. After having tried the prototype for around 10 minutes, they were asked to fill in the evaluation surveys.

4.1.4 Data Analysis

The three subscales from the IMI are scored according to [21], by averaging across all items within each scale respectively. While the author acknowledges that the sample size is small, we will use Pearson's r to correlate the motivation scores against the perceived competence and choice scores. We assume normality in the sample distributions. Responses to the perceived somaesthetic scale will be treated similarly, and included in the correlation with perceived intrinsic motivation. Responses from the think-aloud method and probe questions will be presented were they are applicable or relevant.

4.2 Results

4.2.1 Rating Scales

Descriptive statistics and correlations among study variables are presented in tab. 4.1. As suggested in [21], there is positive relationship between both perceived choice and perceived competence towards perceived intrinsic motivation (however non significant). Irregardless, since these variables are theorized to be positive predictors for intrinsic motivation, it makes sense that we see a result with a positive

Table 4.1: Summary Statistics and Correlations Among Study Variables

Study Variables	**1**	**2**	**3**	**4**
1. Intrinsic Motivation	(0.92)			
2. Perceived Competence	0.58	(0.83)		
3. Perceived Choice	0.59	-0.32	(0.53)	
4. Perceived Somaesthetic	0.45	0.98*	-0.46	(0.19)
Mean	3.81	3.25	5.75	4.18
Standard Error	1.06	0.82	0.48	0.34
95% CI	[0.45, 7.18]	[0.63, 5.87]	[4.23, 7.27]	[3.1 , 5.27]

Cronbach's alpha listed within parentheses
*$p < 0.05$
N = 4

relationship. Surprisingly, there is almost a one-to-one (significant) relationship between perceived competence and perceived somaesthetic experience. On the other hand, we see a negative relationship between perceived choice and perceived somaesthetic experience. Finally, there does exist a positive relationship between perceived intrinsic motivation and perceived somaesthetic experience (however non significant).

4.2.2 Think Aloud and Observations

The first participant (male, age 80, intrinsic motivation score (IMS) = 2, somaesthetic experience score (SES) = 3.33) was hesitant to try the prototype at the outset. After he was convinced to try it by the present therapist, he struggled to understand the concept. While observing the virtual interface, the author noticed that he was unable to get virtual object moving at all, which in turn results in little to no feedback. During the whole 10 minutes, even when allowed visual stimuli, he was unable to navigate around. Admittedly, he was very weak and had a hard time even standing up without frontal support. Hence, he could not create enough force for pressure sensors in the WBB to recognise his attempts. The second participant (male, age 74, IMS = 4.5, SES = 5) did considerably better. Even though he was similarly in need of support, he managed to navigate around the virtual environment with his eyes closed, hence producing a feedback. When allowed visual stimuli, he was able to complete several obstacles and manage to score a point. The third participant (male, age 58, IMS = 2.25, SES = 4.25) simply did not see the logic. When asked to elaborate, he explained that he could not perceive what the goal was. Again, similar to participant one, he was a bit hesitant to give into the experience, and declined to have his eyes closed. He could maneuver around fine, but chose to use the support anyways. The fourth and final participant (female, age 74, IMS = 6.5, SES = 4.16) was surprisingly positive. Of the four participants, she was the most able and/or agile. She still chose to use the provided support. She was able to navigate around using only sound, and even managed to explore an obstacle, which unfortunately she could not escape. After allowing her visual stimuli, she considerably improved, both in terms of game progression and participation factor. Struggling from existing balance problems, she was used to doing various rehabilitation exercises, and explained that she had a hard time pushing herself to maintain them. She explained, in contrast, that she could see herself using the prototype often. However, she expressed that she really did not care about any of the aural elements and that they did not effect her in any way. However, just using the primitive interface to the virtual environment, she could keep going for a long time.

Chapter 5

Discussion & Conclusions

5.1 Reflections On Feedback From User Test

Based on the results from the user test, the somaesthetic experience did not come to the forefront with any of the participating patients. Nor did the intended movement come to be realised. However, it is hard to disregard that these aspects could have been realised given other, more agile patients to work with. A main inhibitor towards the somaesthetic experience, and subsequent movement, was that all the patients required the use of an external support element to participate in the evaluation procedure. However, since the target group of rehabilitation patients does contain a large segment of patients who require extra support, this is a design problem that should be addressed in future iterations. Another thing that inhibits the somaesthetic experience is a problem of attitude. Lets drive this point home by referring to Shusterman's original definition of somaesthetics; *"the critical, meliorative study of the experience and use of one's body as a locus of sensory-aesthetic appreciation (aisthesis) and creative self-fashioning"*, with the keyword here being *creative self-fashioning*. Opening yourself towards somaesthetic experiences and bodily reflections requires a certain internal will to do so. Similar notions was observed in SWAY [1], who reports that users of the artefact had a hard time reflecting on their felt experiences. As such, one would have to agree with Höök et al. [20], that creating designs which quietly cater towards enabling such reflection is extremely hard to achieve.

Admittedly, the current design most likely does not deliver satisfactorily to enable these reflections. I would argue, through extensive experience with the prototype myself, that the gamification aspect of the design takes away the attention from the somaesthetic. Upon reflection, these two approaches to design is contradictory in nature; where somaesthetics is reflective [20, 45] and serious games are goal oriented [4, 39]. For future work, I would suggest to focus on one of the two approaches.

On a positive note, the gamification aspects were generally seen as enjoyable once participants were allowed to watch the virtual environment. This also ties back to how the visual sensory modality is preferred with some user segments. Without taking too much away from the current design, a re-design could focus on including more sensory modalities, such as haptic feedback (e.g. [1, 29]), to evoke the somaesthetic experience.

The results from the correlation statistics (e.g. tab. 4.1) show some interesting results however. First of all, there is negative relationship between perceived choice and perceived somaesthetic experience. This is an apt result, and ties nicely together with our earlier discussion about somaesthetics requiring an will to be effective and enable reflection. Secondly, a positive relationship exists between perceived intrinsic motivation and perceived somaesthetic experience. If we were to give credit to this result, it would support further investigations into using somaesthetics and movement-interaction as factors to increase motivation in a rehabilitation context. Finally, a surprising result is the almost perfect positive relationship between perceived competence and perceived somaesthetic experience. From a psychological standpoint, this could reflect the effects of self-efficacy [25], or as mentioned by a patient early on in this project, a self-reinforcing effect of confidence towards the task at hand. If this would indeed be the case, then there is definitely merit for the use of somaesthetics in the context of balance rehabilitation.

5.1.1 Discrepancies & Limitations

One has to take the evidence provided so far with a grain of caution. First of all, the evaluation was carried out with a very limited and polarized sample size. Secondly, the psychometric variable *perceived somaesthetic experience* has no grounds to prove that is what it is actually measuring. In addition, with a Cronbach's alpha of 0.19, the scale seems to have internal conflict in its consistency. Finally, we have talked about the relationships as if one variable causally explained the other. However, we have no statistical grounds to prove such claims. Hence, perceive the aforementioned discussion as inspiration towards further research into the presented problems and topics.

Investigations Left Out

The effects of the spatial audio has not been addressed during this evaluation. As such, we cannot say with any certainty whether or not they played a key role in the overall experience. This aspect will be left for future investigations.

5.1.2 Implications for Balance Rehabilitation

To answer the question posed in the introduction to this thesis; whether a technological intervention using a somaesthetic design approach to a serious game could be used to motivate patients in their balance exercises, the provided evidence would suggest that it can. A technological intervention such as the proposed prototype, seems to readily fit into an everyday schedule for therapist. It can be used for short a duration by patients, and is both ergonomic and easy to handle. However, the therapists perspective has not been adequately addressed yet. For the possibility of a full integration, more work and dedication should be put into this area.

5.2 Outlook

The current thesis has investigated how to design technologies that could be used with balance in physical rehabilitation context. The approach to the design was to use elements from somaesthetics and movement-based interaction design. We have attempted to navigate through a large design space, from the philosophical ponderings of Shusterman's [45] somaesthetics, to the more concrete field of clinical physio therapy, and have been more successful in some areas compared to others. Designing with the top-down and extremely movement and body focused approach, was a difficult challenge. Coming from projects using conventional approaches to interaction design, changing the perspective inwards and putting one-self directly in the users or, *movers*, shoes requires considerable practice and effort. I will not claim that I have succeeded in this aspect, as this restructuring process is still in the beginning stage for me. However, the thought processes and philosophy involved in somaesthetics and movement-interaction, has begun a process of reflection for myself during everyday life. I would like to acknowledge the great frameworks put forth by authors such as Höök et al. [19, 20] and Loke & Robertson [24] which provides great starting points for beginners and experts alike in the field. I would also like to acknowledge other frameworks, such as Camurri et al. [11], which i did not consider during the writing and development of this project. In future iterations, the ideas laid out during this project could be extended by additional layered frameworks and more nuanced mover-machine interactions, processing and mapping inputs based on more *aesthetic* analyses, such as Laban Movement Analysis (e.g. [24]) and more machine learning capabilities for interpreting higher levels of movement qualities.

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Appendix A

Perceived Somastaethic Experience Scale

A.1 The Scale Items

Please indicate for each of the following questions how much you agree, from 1 = not at all true, to 5 = very true.

1. It was easy to learn how to navigate.
2. After a while, i did not have to think anymore.
3. I was able to stand still whenever i wanted.
4. I never lost control.
5. I had a feeling that my movements were limited (R).
6. It was fun to navigate through sound and balance.
7. It was hard to interpret the meaning of the various sounds (R).
8. I experienced that the sounds were coming from all around me.
9. I thought the sounds were stressful (R).
10. I understood when i had hit, or was close to a goal or an obstacle.
11. I felt stuck most of the time (R).
12. I did not think the sounds were varied enough (R).