EXPLORING THE POTENTIAL OF

RHYTHMIC ENTRAINMENT FOR DESIGN

Frederike Stortelers

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Supervisory team
Project Chair:
Dr. Ir. Erik Tempelman
Mentor:
Dr. Gijs Huisman

In collaboration with:
Glimp
Mentor:
Jefta Vriend

Author:
Frederike Stortelers

SUMMARY

This master thesis explores the potential of Rhythmic Entrainment (RE) for product design applications. The research starts by defining some of the important terms and providing example cases of RE from products and research. A comparison between the cases illuminates the possibilities RE can have for product design and research. [1] RE can create interesting new product interactions, [2] the theory is not applied as broadly across industries.

The second part of this thesis aims to collect and present the knowledge that is relevant to start designing with RE. A framework inspired by embodied interactions is presented, categorizing between human-product-context. The framework approaches designing with RE in an iterative manner, fostering simplicity while acknowledging the complexity of the design process. A product Benchmark test showed that being “hands on” can help designers understand the design tensions. These tensions are caused by the temporality of rhythm, the interaction between factors of the system and the particularity of cases.

Interviews with experts in rhythm (by job, hobby or ability) showed how it can evoke strong emotions and create engaging experiences. The latter occurs when the full system interacts with each other, creating a loop of continuous feedback on the human rhythm, provided by the context or product. In literature, these symmetrical interactions with rhythm are considered valuable, but the practical knowledge and applications are not available.

Therefore the last part determines the factors that influence different levels of responsive interactions from research. To test wether a more responsive interaction is preferable, a research through design case is executed with a design problem from Glimp. It wants to adjust its breathing rhythm to the user and guide it towards the goal rhythm of the exercise. This case resulted in a concept that applies a “configuration” level of responsiveness, while taking skill and data collection into account. The outcome of the research shows that a product can also be too responsive and that time influences sensor choices and the output.

All of the results are summarized in the RE4Design framework that aims to inform designers about the topic in a visual and understandable manner.

The interactive framework can be viewed online:

CONTENTS

BE GROOVY OR LEAVE, MAN

BOB DYLAN

INTRODUCTION

Entrainment refers to the process of two systems synchronizing their movement over time. It was first described by Christiaan Huygens in 1666, when two pendulum clocks set on the same (moveable) surface eventually synchronized their rhythm (Rosenblum & Pikovsky, 2003).

Humans also entrain themselves to rhythms, for example: marching with a group is easier when rhythmic music is played on a drum and musicians unconsciously breathe in the same tempo as the music they are playing (Trost & Vuilleumier, 2013). In healthcare research, the potential for improving human lives through Rhythmic Entrainment (RE) has been displayed: people with Parkinson's disease walk more stable and faster while listening to rhythmic music (Cochen De Cock et al., 2021) and prenatal babies calm down when certain rhythms are played (Krueger, 2011). RE researchers see even broader possibilities; arguing that people are able to access deep emotions through rhythm in music (Clayton et al., 2005; Krueger, 2014; Trost & Vuilleumier, 2013).

However, a comparison between Rhythmic Entrainment (RE) cases from research and products reveals that the diversity of applications in products is limited when compared to the proven (real life) cases. This shows there are untapped possibilities for designers to use RE in their products.

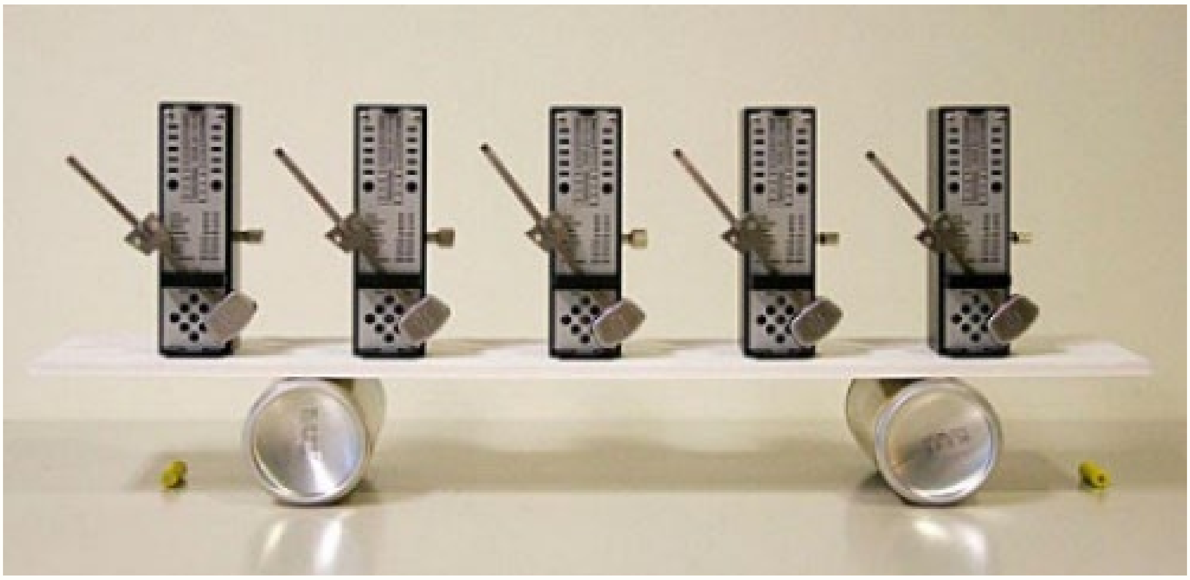

Figure 1: Synchronization of Metronomes

Designers aim to create easy to use and engaging product interactions, to foster positive experiences with the product. The rapid development of the internet and mobile devices has brought extra attention to product interactions that assume cognition is embodied (Klemmer et al., 2006). This thesis shows that Rhythmic Entrainment can facilitate novel, intuitive and embodied interactions.

For a researcher in embodied cognition, RE can provide new approaches and cases to better understand the influence of time on the environment. Rhythm is temporal, and can be seen as an affordance for movement in time (Cummins, 2009; Krueger, 2011).

Looking at recent research and applications, it shows that researchers in RE are familiar with its' potential. However, the knowledge remains theoretical. The practical, hands on approach of designers can illuminate the importance of certain factors that influence the effects of RE. This can possibly steer the direction of research.

This thesis will explore the potential of Rhythmic Entrainment in product design, with the following questions:

1. What is Rhythmic Entrainment?
2. What knowledge is needed to design with Rhythmic Entrainment?
3. How to structure and present this knowledge?

These questions will be answered through multiple research activities, divided over 3 parts:

Part 1 is aimed at familiarizing and sensitizing the reader with the topic, answering question one. This is done by providing definitions to important aspects of this thesis and by introducing a multitude of examples of RE.

Part 2 provides a practical approach to designing with Rhythmic Entrainment. It contains a literature review from the fields of Rhythmic Entrainment, Music and Embodied Interactions. The relevant information is sorted so designers can obtain the knowledge to start designing with RE, answering question two.

A product Benchmark is conducted to remain hands on in the process and discover limitations and possibilities in designing with rhythm. Finally, to further explore the interactions between human and rhythm, some rhythm experts are interviewed. These experts make, steer, design or experience rhythms differently than others and can therefor provide an interesting perspective on the topic. The structure of this part simultaneously serves as a possible structure for presenting the knowledge about RE to designers, answering question three.

Part 3 aims at generating new practical knowledge about RE. A research through design process is executed, researching an unanswered RE question by designing a product for Glimp. Glimp helps people calm down by providing calming breathing exercises and training programs, through audio and handheld "pebbles" that vibrate in the rhythm and tempo of the desired breath. This process aims to answer an unknown about RE (question two), while providing a RE for Design case (question three).

Each parts target different levels of interest in the topic. Part 1 is meant for the reader that wants to learn what RE is. When a person wants to design with RE, it is recommended to read Part 1 and 2. Part 3 is aimed at the engaged researcher that wants to fully understand some of the challenges of (designing with) RE. Finally, for anyone that just wants to "skim through", each conclusion page contains icons that refer to different learnings from this thesis. These learnings are bundled in a visual overview for designers, displayed in part 4.

GLOSSARY AND ABBREVIATIONS

Rhythmic Entrainment
The process of (at least) 2 weakly coupled autonomous rhythmic agents, adjusting their rhythms toward a common phase or periodicity.

Rhythm
A pattern of repeating elements/pulses with a constant ratio between the duration of the pulse and the “silence”.

Tempo
How often a rhythmic pattern (or ratio) repeats itself over a certain duration. Other terms might be: beats per minute, period or rate.

Affordance
The relationships an animal has with certain (sensitive/attuned to) environmental information (resources), these relationships create features that animals have the ability to interact with.

Tactile vibrations
Vibrations that cause force changes on the surface of the skin.

Auditory vibrations
Vibrations that create air pulses and cause force changes inside the ear.

Context
Everything (people, objects, knowledge) in the direct surroundings of the human and the artefact (product) that might contribute to the task.

Resources
Elements from the context of the human that can be used to complete task oriented embodied behavior.

RE
Rhythmic Entrainment

PPG
Photoplethysmogram

RtD
Research through design.

SPOILER ALERT:

RHYTHMIC ENTRAINMENT SHOULD BE EXPERIENCED

&

This thesis research is self-initiated by a product Designer with a passion for music and engaging interactions.

Therefore, this (2 dimensional, flat, static) thesis is supported with Music annotations[1]

[1] Rhythm is Dancer (SNAP!) – The lyrics quite accurately describe parts of this thesis

01

WHAT IS RHYTHMIC ENTRAINMENT?

TERMINOLOGY

RHYTHMIC ENTRAINMENT

Unsurprisingly, Huygen's pendulum clocks differ greatly with humans marching to music. Can we still call it entrainment then?

The term itself has been discussed thoroughly (Clayton et al., 2005; Krueger, 2014; Lomas et al., 2022; Trost et al., 2017), but no definition is widely adopted. Taking all of these approaches into account, the following definition is used for this thesis:

Rhythmic entrainment is the process of (at least) 2 weakly coupled autonomous rhythmic agents, adjusting their rhythms toward a common phase or periodicity.

An autonomous rhythmic agent is a physical or biological system (Trost et al., 2017) that is able to move rhythmically without another system adding energy continuously, the agent is using a source from within (Clayton et al., 2005). A human might kickstart the rhythmic product but does not have to keep moving the product for the rhythm to occur (e.g. turning on a music player).

Autonomy makes the distinction between RE and resonance; the latter has at least one agent that does not have a driver to start oscillating, it needs the other (Trost et al., 2017)

For entrainment to occur, the agents need to interact in some way, without being too strongly connected. Clayton and others (2004) describe a "weak coupling" as a connection that still allows for individuality and errors. The pendulum clocks in the experiment are attached to the same surface, the surface is able to vibrate/move a little. Via the surface, the force of the movement of one pendulum is translated as negative feedback on the movement of the other pendulum and vice versa. As the asynchrony between the pendulums decreases, so does the negative feedback, eventually setting both pendulums in the same rhythm. If the asynchrony in the beginning is too big, the agents will not entrain to one another.

“Adjusting toward” might be similar to the often used “synchronizing”, but the latter implies that the phase and periodicity will be perfectly equal eventually. If the agents are not identical, full synchronization is complicated. Humans physically can’t vibrate exactly like a marching drum, but they can adjust their movements towards something similar (stomping).

Rhythmic entrainment also occurs internally in humans; e.g. neural entrainment of braincells or entrainment of endogenous processes (Thaut et al., 2015). The interaction between the agents is theorized using affordances.

RHYTHM

A rhythm is a pattern of repeating elements/pulses with a constant ratio between the duration of the pulse and the “silence”. To further elaborate on this definition, the duration and perception of rhythm is discussed.

Rhythm can be found anywhere; from long rhythms such as seasons to small ones like our heartbeat. Leaves changing color is a way to indicate seasonal rhythms, which we can adjust to. However, these rhythms are knowledge based; we learned about the existence of the seasons and therefore we adjust to it. For this research, only rhythms with pulses in the 300ms to 1,200ms range will be considered. Shorter durations are not perceived as rhythms but as tones[2], and longer ones require active cognitive work (London, 2012).

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[2] One (your name) – Swedish house mafia & Pharrell Williams: This song starts with a rhythmic “bump” sound (00:12) that speeds up, eventually transitioning into a tone (~00:40), that is used to create a rhythmic melody (00:48) repeating throughout the entire song.

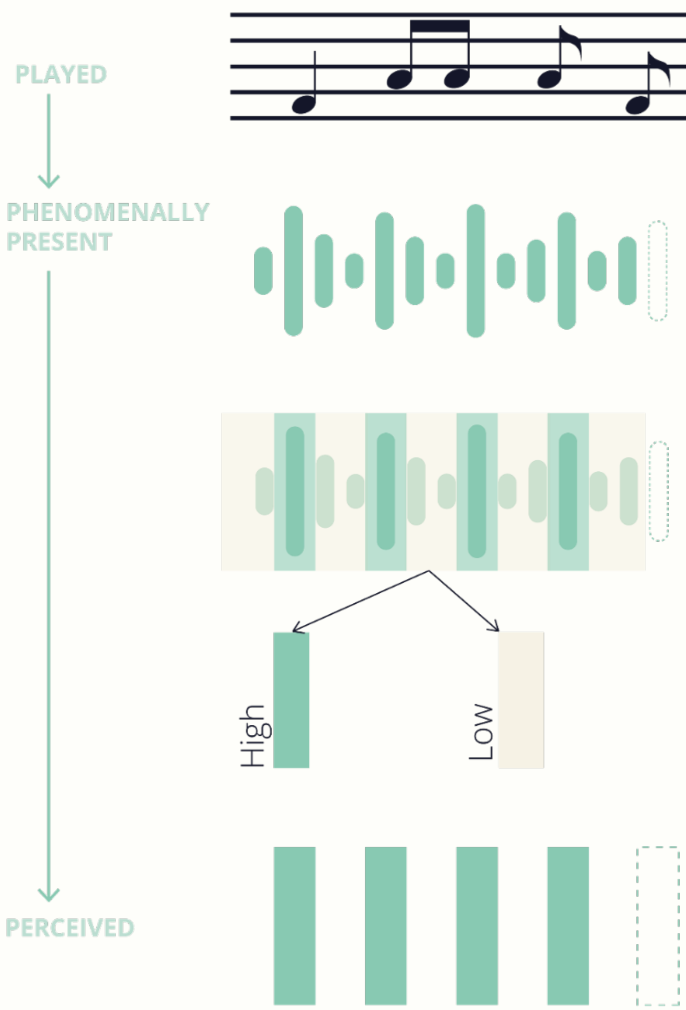


Figure 2: Visual explanation of the stages of Rhythm Perception, Rhythm as..

Most signals from our daily life surroundings are not rhythmic, but when a rhythm is present we can identify it (London, 2012). Perceiving a rhythm in the chaos of stimuli is not as self-explanatory as it seems. For example; music contains a lot of information (instruments, lyrics, volume, rhythms etc.), but most of us are able to understand (tap along, dance, etc.) and enjoy it.

Human perception plays a role in understanding rhythm. A single instrument can play a rhythm as displayed by notes, timestamps, tempo, etc. on the tablature (rhythm-as-played), which generates a sound stimuli (rhythm-as-phenomenally-present). While listening, humans create a hierarchy of "high pulses"; sounds we notice, and "low pulses"; sounds we label as silence or unimportant[3] (Jones & Boltz, 1989; London, 2012). The perception of these pulses create a rhythmic sequence (ratio) that can repeat over time (rhythm-as-perceived). Figure 2 shows how rhythm can be understood as perceptive. In the chapter "Rhythm factors" the design factors influencing the perception of rhythm will be discussed.

[3] *Daydream – I hate models: the bass is immediately noticeable, but when paying close attention, the DJ adds new layers of sounds from other "categories"*

RHYTHM AS AFFORDANCE FOR MOVEMENT

Based on the writings of Chemero (2009) the following definition for

“Affordances are the relationships an animal has with certain (sensitive/attuned to) environmental information (resources), these relationships create features that animals have the ability to interact with.”

affordances is used:

Rhythm provides affordances for movement in time, as illustrated in figure 3. As described earlier, rhythm is perceived by creating a hierarchy of pulses in sound (London, 2012).

It creates a repetitive structure of recognizable pulses, which eventually becomes predictable through the principle of future oriented attending (Jones & Boltz, 1989). This means our brain prepares for the next pulse to occur. While moving, the pulse creates a timeframe (or temporal affordance) for making the movement. For example, when walking to the beat of a song, the attending for the next beat helps coordinate the temporal planning of the next footstep (Cummins, 2009).

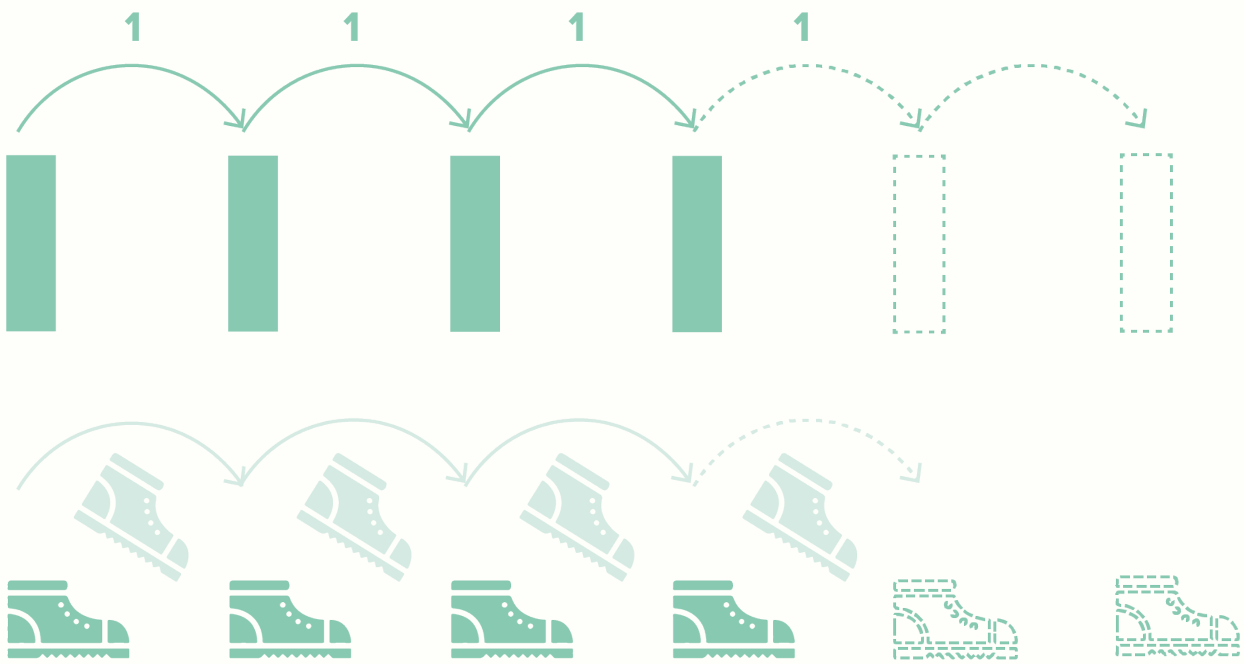


Figure 3: Rhythmic time structure as Affordance for movement

Perception…	Rhythm..		Affordances..	
is relational	can be perceived differently	(London, 2012)	have a relational aspect	(Chemero, 2011)
requires sorting (temporal) impulses into categories	rhythm is sorted in “high” and “low” pulses	(London, 2012)	Analytic attending sorts impulses into categories	(Jones & Boltz, 1989)
is taught	sensitizing is taught	(Phillips-Silver & Trainor, 2005)	Are “hunted” by our perceptive system	(Chemero, 2011)

Figure 4: comparison between Rhythm and Affordances

In our brains, the perception of rhythm is heavily related to movement. Even when the person is instructed to hold still while listening to a rhythm, the brain areas related to motor coordination are active. The same motor areas are also active when the person is moving to the rhythm (Thaut et al., 2015; Tierney & Kraus, 2015; Trost & Vuilleumier, 2013). Hearing a rhythm “prepares” the body to move accordingly.

Affordances and rhythmic entrainment have common explanations for certain aspects of perception, as shown in figure 4.

Studying RE through the lens of affordances for movement is valuable for product design for multiple reasons. Firstly, affordances are recognizable for designers[4]. Design education often includes the understanding of affordances (Norman, 1999; Technische Universiteit Delft, 2020), although their definition is often limited to merely the physical affordances of e.g. the handle of a coffee mug. Secondly, the theory of affordances is further developed and can therefore provide some framework for the process of designing with Rhythmic Entrainment. Embodied theory can provide helpful ways to scope the rhythmic context, as Embodied theory is familiar with analyzing complex and large systems. Part 2 uses a framework provided by Embodied theory. Finally, it has explained some inconsistencies in RE theory in the past (Krueger, 2014; Windsor & De Bézenac, 2012). For example, why we subconsciously and uncontrollably entrain our motor movements while listening to music (Janata et al., 2012; Tierney & Kraus, 2015). Researchers can use the theory of affordances to explain some aspects of Rhythmic Entrainment.

[4] Flower – Moby: due to its’ rhythm and the vocal indications (up & down) it has been used a lot for workouts. It can provide an indication of time while doing squat exercises.

CASES OF RHYTHMIC ENTRAINMENT

Product design builds on prior knowledge, researching already existent cases is common practice. An analysis of (researched) real life cases of RE can inspire the designer, explain the topic and make the designer more sensitive to recognizing rhythms in daily life. An analysis of rhythmic products can reveal some opportunities and limitations of RE. The cases were collected from research papers about the topic. They had to [1] be researched as rhythmic entrainment, not any related topic. [2] be somewhat related to natural cases of RE. This means excluding researches that were conducted entirely in a lab without any elements that resemble daily life. The full list of cases can be found in appendix A.

Children were able to focus better in class when a rhythm was playing (Trost et al., 2017). Runners lasted longer while listening to rhythmic sounds matching their cadence (Bood et al., 2013) and people feel more connected when they have a shared music experience (Fink et al., 2022; Krueger, 2011).

A product portfolio analysis was performed by looking at the following keywords; rhythm, entrainment, music, vibration, and a few synonyms: harmony, synchrony, beat. The term rhythmic entrainment does not have to be mentioned in the description in order to be considered for this analysis because of the large variety of similar terms. The analysis includes products available to the consumer and a few (not yet available) products from startups. The latter represents current developments, but it should be noted that their feasibility and effectiveness has not been proven. A brief description of each of the products can be found in appendix A.

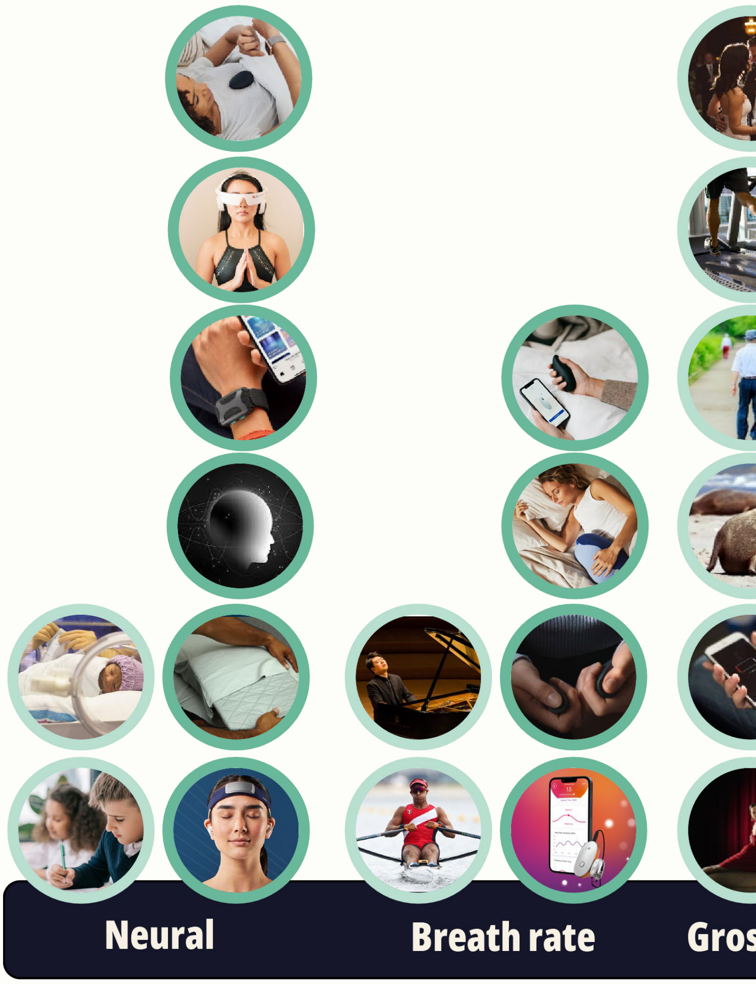
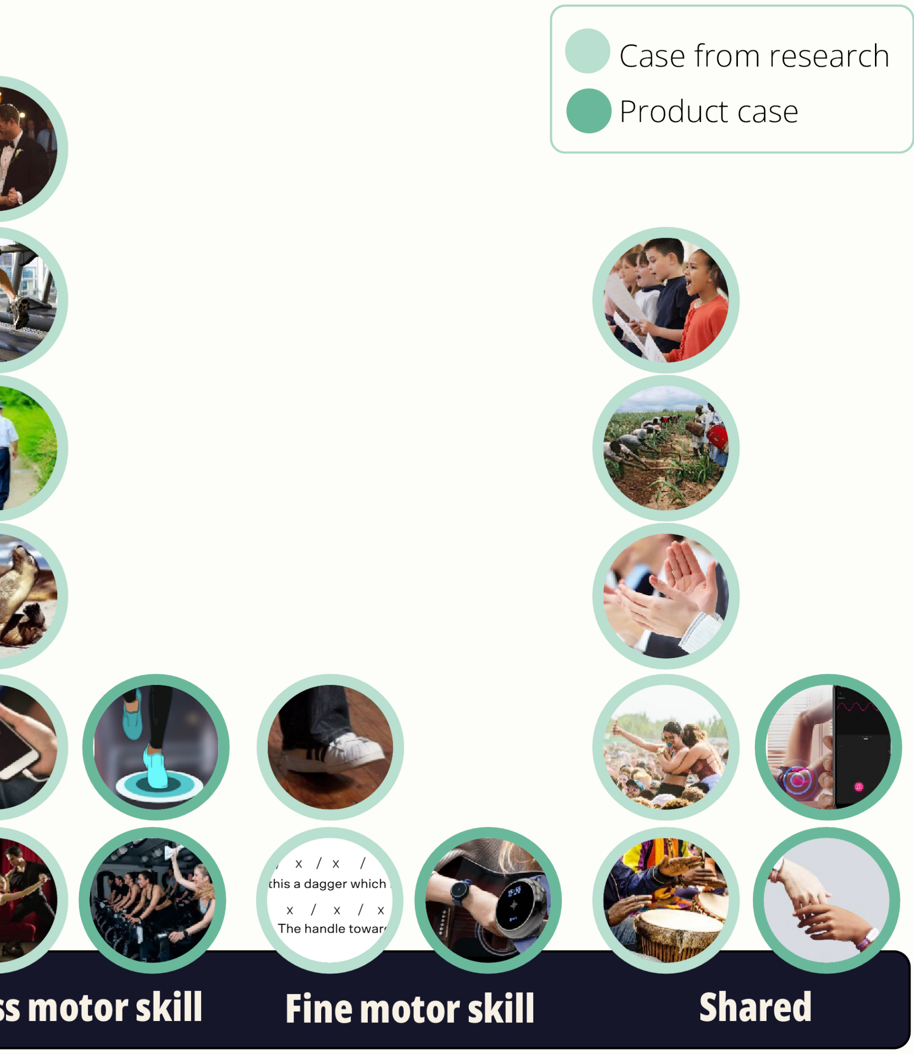


Fig. 4: Comparison of RE cases from Research and p

The cases are analyzed by sorting them on the rhythm that is influenced. The categories are: breathrate, neural signals, body movements (gross and fine motor skill) and social (shared) rhythms.
As seen in figure 4, the product cases are mostly aimed at neural rhythms and breathing rhythms, products such as Somnox aim to create mental peace through breathing (Somnox, 2022). Only a few exceptions exist; Soundbrenner is a haptic metronome to help musicians stay on beat (Soundbrenner, 2022) and Lovense makes sextoys that can be controlled by a partner at a long distance (Lovense, 2023).

On the contrary, the research examples are mostly aimed at shared rhythms. For example; reaching flow state during group drumming sessions and feeling more connected with others at a concert (Trost et al., 2017).



products

CONCLUSION PART 1

Using rhythmic entrainment in product design will be stimulated if the knowledge about the topic is clearly communicated and presented to designers. Different terminologies, usages and research methods make it complicated to find one suitable definition for rhythm and entrainment. Presenting RE to designers thus requires creating a mutual understanding of the definitions of these words. Viewing rhythm as an affordance for movement can make RE easy to understand by designers, as they are familiar with affordances.

By providing a plethora of examples of RE, designers can better understand the value and sensation of RE. Likely, an average person does not think about rhythm a lot[7], let alone Rhythmic Entrainment. By showing some examples and connecting it to recognizable situations, the designer becomes more aware of the large variety of rhythms and the effect of RE in daily life. The cases show that humans can have strong emotional and behavioral responses to it. However, this can be a personal experience; the perception of rhythm can be different per person.

Comparing the known research cases to the products available on the market revealed that the theory of RE is not put into practice. It also showed that most RE products are in the same industry of mental health, even though the research examples show that the applications can be much more broad and diverse.

The next section presents the (designable) factors that influence the effect of RE.

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[7] Back on 74 – Jungle: In the videoclip of this song, the dance is made to the rhythm rather than the (more common) melody. The huge popularity of the dance made people aware of the importance of rhythm.

WHAT IS RHYTHMIC ENTRAINMENT?

The perception of Rhythm is personal and can be emotional.

Understand the definition of Rhythm, Rhythmic Entrainment and Affordances.

Use examples from research and products to better understand the topic.

Rhythmic Entrainment is applicable in multiple product categories but is barely used outside of (mental) health tools.

There is a disconnect between the theory and the application of it.

02

RE 4 DESIGN

INTRO

The previous part has shown the variety of rhythmic interactions and has hopefully inspired some designers. Knowing the *what* and *why* of Rhythmic Entrainment is step 1, this chapter is aimed at explaining the *where, who, when* and *how.*

The structure of this section is based on the structure of Embodied behavior according to Wilson and Golonka (2013), which is discussed next. It sorts the information available about RE, in an interactive and embodied manner. Additionally, a product Benchmark is conducted to learn more about the design challenges. Finally, interviews will illuminate interesting aspects about the interaction in rhythmic environment. A visual overview of the chapter is shown in the figure to the below.

THE FRAMEWORK

Analyzing the context of the RE product can be complicated due to the large amount of stimuli. As shown in the previous section, each stimulus might have a different meaning for everyone, even over time[8]. Context is thus approached from the definition of affordances:

> "The environment is meaning laden, in that it contains affordances, and affordances are meaningful to animals" – Chemero (2009)

It is helpful to look at the context in its physical aspects, but also in the relation between the human and these aspects over time (A. D. Wilson & Golonka, 2013) The contextual aspects are the "resources" available to execute task oriented embodied behavior. Task oriented behavior means that the behavior is executed because the human has a task/goal they want to achieve. For designers, the "rhythmic task" refers to the goal of rhythm in the product. Defining this goal helps in scoping the design research, more on this later.

The factors that influence RE are split into 2 types of resources. [1] Physical resources refer to phenomenally present elements in the system: the human, product (artefact) and the context (environment). [2] Relational resources refer to resources that only exist when there is an interaction between two (physical) elements of the system. For example, while failing to reach for the cookiejar, a sibling can become the "stepstool" that helps in reaching the jar. In another situation the sibling might be "an annoying sound", the relationship between the two siblings changes when the task changes, but their physique does not.

[8] Pumped up Kicks – Foster the people: At first this song might sound very cheerful, but when the context of the lyrics is added, the song becomes very sad.

RHYTHMIC TASK

In this framework, "rhythmic task" refers to task oriented embodied behavior that can be influenced by RE. A person has a rhythmic task they want to achieve and solves it with the product. For example; a person might have the task of traveling some place quickly, rhythm can make the person walk faster[9] but it cannot carry the person like a car would. The product should have a task related to a rhythm in order to be suitable for RE for design.

This chapter categorizes the effects of RE into 5 different tasks (Trost & Vuilleumier, 2013): perception, autonomic physiological, motor planning, social behavior and emotion/mental state. Each category has different (bodily) areas of effect and context related challenges. Bear in mind: in reality the effects are not as clearly separated, as they often occur simultaneously.

The product might be simultaneously in multiple categories. For example; a rhythmic breathing product can influence the autonomic physiological breathing pattern, related to daily life breathing. However, in breathing exercises, the breathing is steered consciously, which makes it motor planning. When the exercises are aimed at achieving some mental state or emotion (e.g. relaxation) it is more related to the category of emotions and mental states. Researching all of these fields takes a lot of time. Choosing one will help in simplifying the design process, as it scopes the large amount of information that is available. A designer can determine which category is the most influential or important to their case and iteratively add information from other categories if needed.

To help the search for valuable information, the upcoming sections explain each category with a research example, areas of the body it affects, a challenging aspect of the category and a product example.

[9] *Jump – Madonna: this song has 120BPM, which matches a fast walking pace.*

PERCEPTIVE

This task refers to the human perceiving the rhythm as such. As said before, it refers to the ability of recognizing a rhythm in the sonic context. Without this, the other RE tasks can't occur.

The brain regions related to motor control are active when the rhythm is perceived, even when the person isn't actively engaging with the rhythm (Tierney & Kraus, 2015). Krueger (2014) argues that the brain entraining to the rhythm affects all of the other tasks as well. Therefore, creating a product for the purpose of perceiving the rhythm might be redundant, especially considering that measuring this task requires looking at brainwaves.

However, tools that help with understanding the common (western) perception of the rhythm can be interesting. DJs often use software to determine the beats per minute of a song, so they can accurately mix their music. These programs analyze a section[10] of the song on the tempo of bass pulses, a metric that a lot of (western) people use for determining their dancing tempo (Clayton et al., 2005).

AUTONOMIC PHYSIOLOGICAL

Bodily rhythms controlled by the autonomic nervous system can align to external rhythms. Mostly heartrate and breathing rate have been researched, for example in listening to music (Ghandeharioun & Picard, 2017; Trost et al., 2017).

Naturally, there is a physical limit to the tempo of these organs. They can slow down or speed up due to activity, but remain within boundaries. When an extremely slow or fast rhythm presents itself, the heart and breathing rhythm will align their period and phase only partially (Khalfa et al., 2008; Trost et al., 2017).

A product that uses this task is Sensate. It uses audio and gentle tactile vibrations to the chest (vagus nerve) to activate the parasympathetic system. This is the neural system related to a resting heart and breath rate (Sensate, 2023).

[10] *Heroin – The Velvet Underground: shows that assessing section of the song is not always helpful, as the song speeds up a lot.*

MOTOR PLANNING

Perceiving a rhythm improves the ability to plan and correctly execute movements. It can increase accuracy and lower mental effort, as shown in research to improving walking patterns of Parkinson patients (Cochen De Cock et al., 2021).

This task can affect a large variety of areas in the body, from finger tapping (Thaut et al., 1998), to running (Bood et al., 2013), to bobbing the head (Janata et al., 2012). These body parts differ a lot, searching for information that is specific to movement the product wants to influence is helpful.

For example, "Rocycle" spinning class instructors choose the music of their class based on the movements of the exercise on the bike. When the exercise requires a lot of pressure on the legs, the movement and music becomes slow. High speed paddling is accompanied with exciting fast music to match the intensity of the exercise.

SOCIAL

This effect refers to the motor synchronization of two humans. For example; while walking, humans often unintentionally align their walking pattern. Deliberate synchronous movement of people can create a deep sense of connection and sympathy between them (Keller et al., 2014), e.g. slow dancing with a partner[11].

Defining the resources of this task can be complicated because it can occur between humans alone, but also in addition of an external rhythm. The examples named above differ in their intention as well. Aligning the walking patterns happens unintentionally, while dancing with a partner requires the intention to dance together.

Lovense is the only (known) product that creates social connections through rhythms, for long distance partners. The rhythm of the tactile vibration of the sextoy is determined by the movement of the sextoy of the partner, or through manual control in the app (Lovense, 2023). The field of teledildonics is rapidly developing and is thus interesting to research for other social rhythmic products.

[11] Slow dancing in a burning room – John Mayer: The tempo of the song is perfect for couples to dance to while embracing each other, allowing for an easy swaying motion. (However, don't start dancing to this song until you understand the lyrics)

EMOTION/MENTAL STATE

It is known that music can elicit strong emotions and change the mental state of a person[12]. Music therapy has been used to calm down premature babies and create an emotional connection with their parents, even in the chaotic environment of an intensive care (Krueger, 2011). Rhythmic entrainment has been considered as a mechanism that explains the emotional reaction to music, but the importance of rhythm in this effect depends on which model for emotion is applied (Trost & Vuilleumier, 2013).

The discussion and limited understanding of emotion make this task challenging. A simple "plug and play" rhythm for a certain emotion or mental state doesn't exist, as they are personal and case specific. Some connections have been researched in specific cases, for example attempting to connect tempo variables to emotions (Janata et al., 2012; Khalfa et al., 2008).

Many of the existent RE products are aimed at steering mental states through rhythm. Apollo neuro argues it can stimulate all kinds of mental states (energetic, relaxing, social, etc.) by applying (continuous) vibrations to the wrists or ankles (Apollo Neuro, 2023).

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[12] *Silver springs – Fleetwood mac: in this song, a deeply sad Stevie Knicks voices her feelings about her divorce.*

PHYSICAL RESOURCES

CONTEXT

The context refers to the scenery/environment/surroundings where the product is used. However, this location likely contains other humans, objects and stimuli. Wilson and Golonka (2013) approach this complexity by using “resources”; elements from the system that can be used to complete task oriented embodied behavior.

To understand any behavior, an extensive list of (possible) resources is made and the most important ones are selected. Some aspects of the system might not be resources for performing this specific task. It requires determining which resources are part of the human, context and/or product (Wilson & Golonka, 2013). Designers can simplify this process by sketching a use scenario and tagging elements, as shown in figure 6.

Scenario sketching is an effective way to analyze (RE) products, as the scenario includes time as part of the story. It is impossible to describe all of the influences of time on an environment.

To simplify the analysis, the designer should only research the relationships between resources that might change due to the duration and frequency of interactions with the product. For example, through frequent practice with a meditation tool, the human is able to ignore background sounds in their environment for a longer time. The relationship with the resource “sound” changes over time due to the interactions with the artefact. The attention (focus) to execute the task might change, more on this in section: “motivation & attention”.

Figure 6: Example of a scenario frame with tagged resources

HUMAN

For RE to occur, the human needs to have the ability to entrain to the rhythm (M. Wilson & Cook, 2016). This means the human is physically able to perceive the rhythm as and is physically capable of making the movements from the entrainment task[13]. For example; a human does not have the ability to swing one's body exactly like a metronome (figure 7), but with their fingers they might achieve a similar movement.

Rhythms are temporal, therefor the senses available to perceive rhythms need to respond quick enough. Slow senses such as scent and taste are not suitable for displaying a rhythm. To perceive a stimuli as being part of a rhythm, a quicker response is required (London, 2012) Visuals, haptics and audio are quick enough. Although visual stimuli can easily be created through all kinds of methods, this sense will not be considered for this analysis for the purpose of scoping.

That leaves audio and tactile as senses to apply rhythms to. The placement of the audio can be determined by the context, mostly if the audio can be heard by other people and the distance of the human to the speaker. Haptics is a bit more complicated because humans have multiple receptors for touch, all with their own purpose and located at different locations (MacLean, 2000). This means some locations on the body are much more sensitive to certain interactions, which might influence the placement of the haptic rhythm. A slight misplacement of the haptic rhythm can have an effect on the experience, as shown in the results from "Benchmark".

Figure 7: example illustrating "Ability"

[13] Traag – Bizzey, Jozo & Kraantje Pappie: The song has a well pronounced, easy to step on beat. The popularity can be attributed to people being able to dance to it easily.

ARTEFACT

Vibration

A product designer will likely think of tactile vibrations before thinking of the more common audio vibrations. The difference between the two lies in the main method of perceiving the vibration. Audio speakers vibrate the air and vibration motors vibrate the skin. However, both methods can overlap; vibration motors also produce sound and audio with a lot of bass can vibrate skin through the air. Recent developments in tactile motors show this overlap as well; a Linear Resonant Actuation vibration motor has a similar working mechanism as a speaker.

Displaying the Rhythm

The actuators for haptics have a large variety of working mechanisms and thus interactions. The most commonly used actuators in existent products are vibration motors but motorized mechanisms can be considered as well. There are 3 commonly used vibration motor types, each with different working mechanisms and thus sensations (precision Microdrives, 2023). Deciding which type to use depends on the application; the size, force, pitch and precision can drive this decision.

Rhythm Factors

A few factors of rhythm are important to consider for design. **The ambiguity** of the rhythmic source refers to which extend the impulse can be interpreted (perceived) differently. In ambiguous (mixed) audio, such as music, the rhythm-as-perceived can be different per person (London, 2012). A single tick from a metronome is straightforward and hard to perceive differently; the high pulse is the (exact same) tick and the low pulse is the silence. Most people will thus perceive the same rhythm (Khalfa et al., 2008) when using a metronome. A designer can start with low ambiguity rhythms and increase the complexity throughout the design process, checking at each iteration if the users interpret the rhythm as intended.

To simplify designing with rhythms, the distinction between **high pulses and low pulses** will be used, as shown in figure 8. A designer has to decide what will be the high and/or low pulse and if the tempo is of importance.

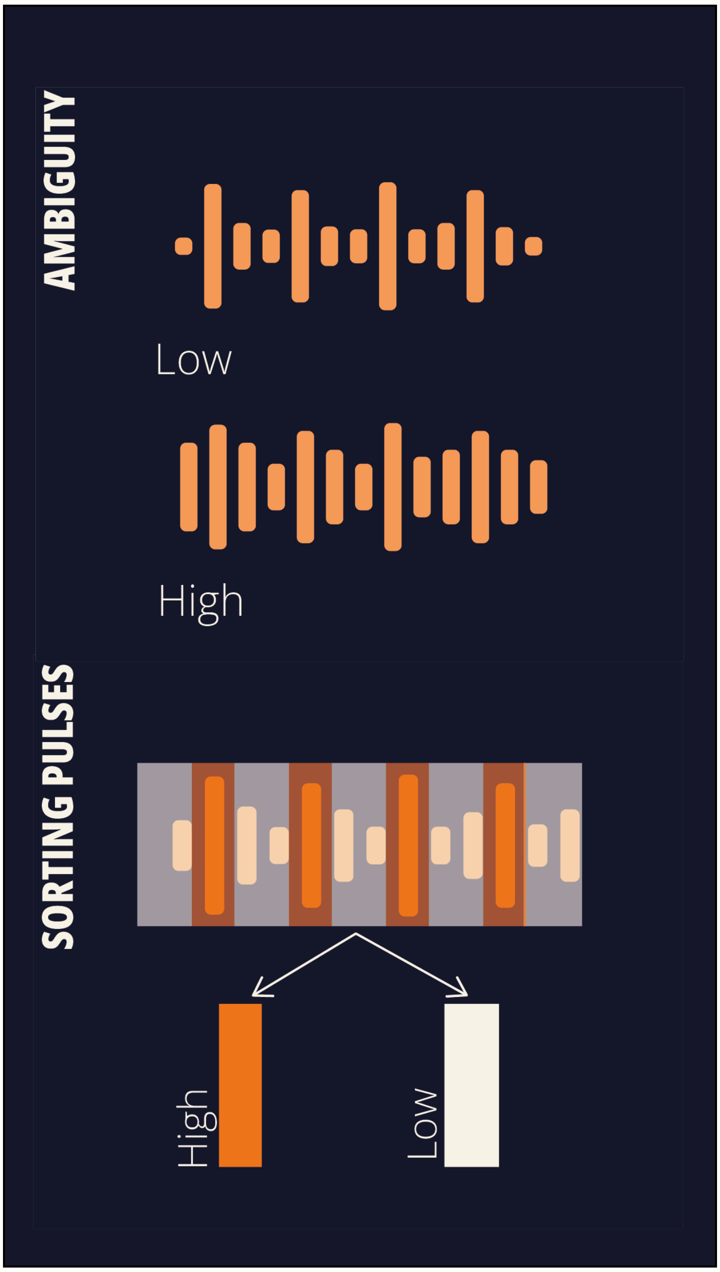


Figure 8: visual representations of Rhythm Factors

To avoid confusion about **tempo,** the definition will be as follows:

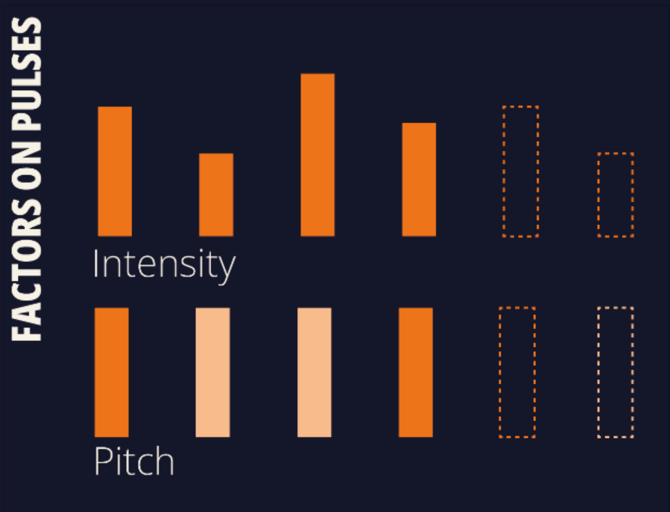
The tempo refers to how often a rhythmic pattern (high and low pulses in a determined ratio) repeats itself over a certain duration.

A higher tempo means the duration of the entire rhythm is shorter, achieving a higher tempo. The duration ratio between high pulses and low pulses remains the same, otherwise the rhythm is changed.

Pulses can differ in their intensity tone frequency (pitch) and duration.

The intensity of the pulse can also be considered the **volume** (of audio) or **force** (of haptics). Naturally, a pulse with a higher volume/force will be perceived more easily than one with a low volume/force. However, there is an upper limit to what feels comfortable, also in tactile vibrations.

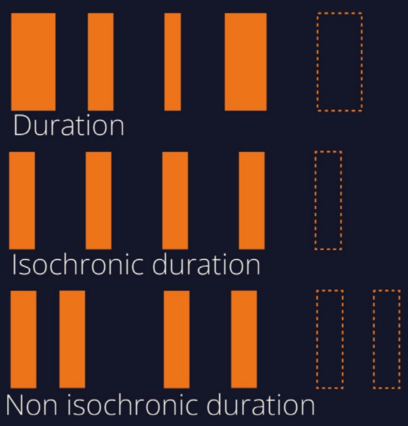
Frequency of the pulse refers to the note or pitch in music. The pitch adds “color” to the sound. In selecting a pitch it is valuable to use the notes humans are familiar with. The Heptatonic tone scale is generally accepted by Western listeners, it defines which frequencies are considered desirable (Clayton et al., 2005). This might not appear as important for tactile vibrations. However, people are able to perceive pitch in tactile vibrations and as said before tactile vibrations do not exist without some audio vibrations.



Duration refers to the time a pulse can be perceived as being different from another pulse. A fading tone might eventually be perceived as a silence, therefor it is important to know the abilities of the senses used to display the rhythm. (London, 2012)

There are 2 types of **durational patterns** in rhythm. If the duration of the low pulses remains the same throughout the entire rhythm, it is considered an isochronous rhythm. For example, a tick of a clock.

Non-isochronous rhythms have different durations of low pulses within one rhythm. For example, a heartbeat is non-isochronous because the time between the pulses differs; the lub-dub (closing of the chambers) is followed with a silence (opening of the chambers) that takes longer than the time between the lub and the dub. Understandably, isochrony can add to the complexity of the rhythm, but it can also make the rhythm more engaging.



In selecting the values for any of the previously named factors, it is easy to fall into the rabbit hole of research that attempts to assign meaning to a certain value of e.g. tempo, pitch, ambiguity and intensity. High tempos have been related to increased heart and breath rate (Trost & Vuilleumier, 2013), the pitch of a cats' purr (40Hz) has been related to relaxation and ambiguity has been related to danceability (Janata et al., 2012). The researches often contradict each other and are highly situational. These types of research could be taken as a starting point for the design, not as a rule.

Designers can also look at daily life situations related to their rhythmic task or target user to define these values. Creating products with recognizable vibrotactile patterns based on real life has shown to be effective in communicating emotion (Macdonald et al., 2020). Recognition of humanmade sounds[14] (clapping, singing) also increases the ability to understand the rhythm (Clayton et al., 2005).

[14] *Baiana – Barbatuques: Song with mostly humanmade sounds.*

BENCHMARK

A benchmark test is often used in product design to help designers get familiar with the products that already exist on the market. It can give points of reference for assessing the quality of the designed product, but it can also reveal some of the challenges the product designers can expect. For this research it is also a way to get familiar with the practicalities of rhythmic entrainment for product design. The following questions will be discussed:

1. Which factors are important while studying RE interactions?
2. Which design tensions can be found?

Method

From the analysis of current products, a few products were researched: Apollo Neuro, Glimp, Magic Motion, a Tactile Transducer, Hapticlabs kit and Moonbird. Each product is tested separately as described by the instructions. The researcher first goes through one round of using the product and then fills in an information sheet while having the product nearby.

The sheet contains basic information about the intended use content, the vibration pattern, the sensation on the body and some notes. For the sensation on the body, a visual of a body is used in combination with a list of words to describe vibrations, which can be found in appendix B.

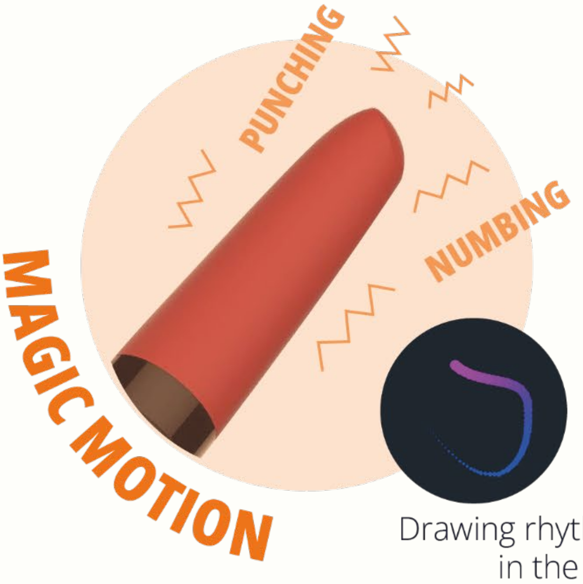
Results

The results of the benchmark can be found in appendix C.

Conclusion

A summary of the most interesting insights can be seen on the right. The main insights are:

1. Experiencing different rhythmic products helps understand the design tensions.
2. Finding the right words to describe rhythms and vibrations can be complicated.
3. Audio vibration and tactile vibration are closely related.
4. Frequent changes in the rhythm causes confusion
5. Actuator choice is determined by many factors.
6. Products often allow for adjusting the intensity of the vibration.



Drawing rhythms
in the app

Heavy and big

Forceful vibrations

Bracelet shifts when moving,
changes the vibration sensation

Pattern changes every 20s,
confusing and distractive

Shame due to aesthetics

Commonly occuring features:

App controlls

Changeable intensity

Unique, organic feeling actuator

Confusing whirring sound

RELATIONAL RESOURCES

PLACEMENT

The location of the artefact (and its rhythmic actuator) in relation to the human is only partially determined by the rhythmic task, for example: music in a club might influence the motor planning in our feet, but the music does not have to be played at our feet for us to entrain to it.

The rhythm needs to remain perceivable when the rhythmic artefact is at a greater distance from the human. Audio rhythms can be altered in volume with ease, and in louder surroundings the artefact can be brought closer (e.g. with headphones).

Tactile vibrations are a bit more complicated in remaining perceivable. Firstly, as said before, some sections of skin are more/less sensitive to certain frequencies and intensities of the vibration. Secondly, simply increasing a factor (tempo, force, pitch, etc.) of the tactile rhythm will not always result in increased chance of perception. Instead it can cause "vibration numbing", which is the uncomfortable sensation of numbed skin due to vibration. Finally, the artefact needs to be in contact with the skin, which often means looking into wearables.

There is a lot of information available on this topic (MacLean, 2000). The main takeaways for designing wearables for RE: [1] the wearable should not shift due to movement. As shown in the section "Benchmark"; [2] the location of the wearable can be determined by the value it wants to measure, as shown in figure 9.

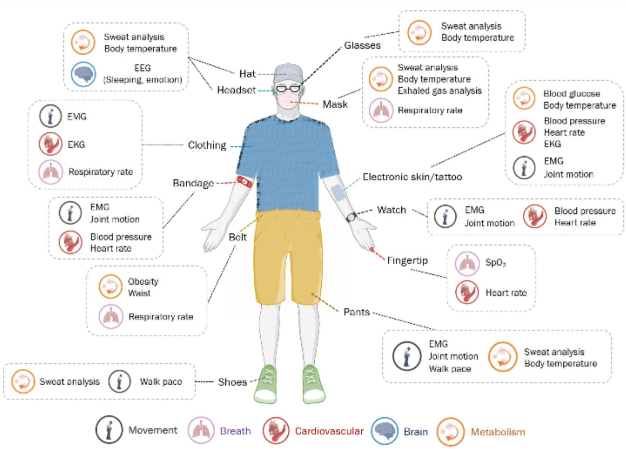


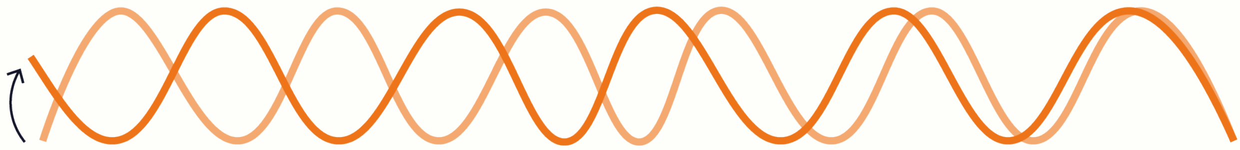
Figure 9: Body zones suitable for wearables (Lu et al., 2023)

HUMAN-PRODUCT INTERACTION

Strictly speaking there are two forms of interaction between 2 rhythmic agents in Rhythmic Entrainment. [1] Symmetrical entrainment: when both agents entrain to each other, meeting with their rhythm in the middle. This occurs when two people make music together. However in products, a more common type is [2] asymmetrical entrainment: only one of the agents adjusts to the rhythm of the other. For example, when a human dances to (pre)recorded music, no matter how frantic the dance, the music will not change[15].

Symmetric RE between a human and a product is rarely seen, even though it happens often in real life. Research cases have shown it is valuable for the effects and comfort of the entrainment process (Bood et al., 2013; Cochen De Cock et al., 2021; Fink et al., 2022; Ghandeharioun & Picard, 2017; Jung et al., 2021).

However, it requires the artefact to be able to sense the user rhythm and process it before the next rhythm starts. The way (speed, goal rhythm) the product adjusts its rhythm is important as well. More on this later in the section "Character".



Asymmetrical

Symmetrical

[15] *Dancing with myself – Billy idol: song which stimulates frantic dancing.*

MOTIVATION AND ATTENTION

Cognitive states such as motivation and attention are considered some of the main determinants for successful entrainment in animals (M. Wilson & Cook, 2016). Janata et al. (2012) showed that uncontrollable movement can occur while passively listening to groovy music; people started bobbing their heads or tapping their feet[16] without having any intention to do so. Non-intentional reactions display the strong influence rhythms have on humans; it is hard to control. This control can go even further; precise motor entrainment can occur without the person noticing a change in tempo (Thaut et al., 1998). The body responded to the tempo change, without the person being aware of the change.

Consciousness complicates RE theory, can an impulse be considered perceived if the body responds to it, but the human is unaware of the rhythm? Or if the human does not have the task of aligning to it? Some argue that humans always interact with a rhythm; even a passive or unaware listener has an active and action ready (attending) brain (Jones & Boltz, 1989; Krueger, 2011; Tierney & Kraus, 2015; Windsor & De Bézenac, 2012).

Interactions in RE get complicated when one of the rhythmic agents has consciousness and free will, product design has to take motivation to entrain into account. To simplify the design process it is assumed there is a distinction between spontaneous (subconscious) and intentional (conscious) interaction with the rhythm. The ethics behind pursuing the creation of a product that subconsciously influences human behavior might be questionable. Therefor it is advised to only focus on interactions where the human has the ability to perceive the rhythm and has (at least had) the intention of entraining with it.

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[16] *Soul with a capital S – Tower of power: can be considered a Groovy song that stimulates spontaneous movement.*

If no attention is directed towards the phenomenally present rhythm, the animal will not sort out the information required to perceive the rhythm. It works the same in humans, for example: skilled dancers are not actively focusing their attention to engage with the rhythm all of the time, only when learning a new choreography (Trost & Vuilleumier, 2013). The motivation to dance on beat is conscious, but the process of entraining to the beat requires no attention after some time.

For the designer this means the user has to have the conscious goal to entrain, without always having the explicit need of fully focused attention. A more educated user might not need full focus to entrain to the rhythm. Factors such as fatigue and distractive impulses from the environment can influence the attention.

SKILL & FAMILIARITY

Before the human interacts with the artefact in the intended context, they might have had other interactions with resources from this rhythmic task[17]. This can result in a difference in skill and preference.

Accurately moving to and recognizing the rhythm can improve over time through practice. The task performance improves and requires less energy/attention to execute. (Clayton et al., 2005; Trost et al., 2017; M. Wilson & Cook, 2016)

In one experiment, babies learned how to understand rhythm by being wobbled up and down by their caretaker (Phillips-Silver & Trainor, 2005), prior to the wobbling they did not recognize the rhythm in the music. This also explains why familiarity can play a role in the effectiveness of entrainment, more familiar (or in some cases: preferable) rhythms are easier to entrain to (Trost & Vuilleumier, 2013).

This means culture can play a role as well, people of African origin often walk in polyrhythm; the legs move in a different rhythm than the arms (Clayton et al., 2005). They might be more sensitive to polyrhythmic music than the traditional Western rhythms that use the same 4-4 pattern for nearly every music piece.

[17] *Carmen – Stromae: music often uses "samples" from other pieces to make it recognizable. (In this song it has a poetic meaning as well)*

CHARACTER

Rhythms can communicate character, as shown in tactile vibration research (Macdonald et al., 2020; Seifi et al., 2015) and as shown by our ability to assign character descriptions to music[18]; cheerful, energetic, uplifting, etc. This is the result of an interplay of factors that influence rhythm, unfortunately there is no go-to pitch or tempo that will always result in the objective perception of the same character.

Designers are familiar with designing with character, a consistent character throughout the entire product will make it more understandable (Technische Universiteit Delft, 2020). Therefore, the designer should consider the character of the rhythm as well. An example from the benchmark shows the intuitive connection humans make when perceiving vibrations; the breathing coach device "Moonbird" has accidental (auditory and tactile) vibrations caused by the motor. These resemble "raspy breathing" and thus distract from the intention ("calm breathing") of the product.

In symmetrical entrainment between the human and a product, the character of the product becomes even more important. When the product notices the human is not in the intended rhythm, it can adjust its own rhythm. The artefact can adjust itself more towards the rhythm of the human or more towards its own goal rhythm, this can create the sensation of the existence of character. A device that "steered" the user into a better breathing pattern by squeezing their chest was judged as unpleasant. When the same device followed the movement of the chest of the user, it was considered "supporting" (Jung et al., 2021). The importance of the goal rhythm and human rhythm can be determined by the designer, although this might also change over time. Figure 10 shows how the product can have a different character in the timing of the next pulse. The designer can decide how important the user timing is compared to the goal timing. After each user input, the product can determine the timing of the next pulse with a "weighted" score.

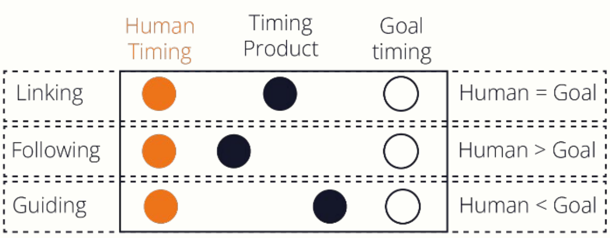


Figure 10: Importance of the human timing vs. the goal timing

[18] *Welcome to the Internet – Bo Burnham: this song uses rhythm and tempo to illustrate the obsessive and disturbing character of the internet.*

INTERVIEWS

The last chapter showed that interaction between the artefact and human is subject to many factors that influence the effect of Rhythmic Entrainment. To further explore this interaction, interviews are conducted with people that interact with Rhythms in an unique manner on a daily basis. The interviews aim to answer the following question: *What can already existent rhythmic interactions teach us about creating engaging and intuitive rhythmic products?*

METHOD

The interviews were held face to face and recorded on an iPhone. The recording is transcribed and tagged for common themes. The questions are about 3 themes:

1. Their definition of rhythm.
2. The environment of their rhythmic experience.
3. The character of (un)desirable rhythmic interactions.

The full list of questions and results can be found in appendix D.

Steve Toet on going to parties with a hearing disability:

"I see everyone enjoying the music, I see their emotions and movement, but I do not feel it. I'm outside of it all"

DISCUSSION

Each of the participants voices their strong emotions towards rhythm. Being out of rhythm feels "horrible, excluding, slapping". Being 80% deaf, Steve Toet often feels left out/estranged when people are enjoying music that he cannot perceive. Jikke feels disgust when one of the choir members is out of rhythm.

JEANS on his context providing feedback while DJ'ing:

"I want to be close to my crowd so I can feel them stomp to the music, then I know if I'm doing it right"

Being in rhythm feels "connected, unifying, calming", to the point of nearly achieving a trance-like state. The factors that influence a good rhythm are hard to pinpoint, according to the musicians it is a "gut feeling".

Strong positive emotions are evoked when the context of rhythm making "responds" to the human and the stimulation is multimodal. JEANS wants to feel the bass of the speakers ("swim in the rhythm") and he prefers being close to the crowd so he can feel the rhythm of their movement through the floor. Jikke recognizes this aspect when she sings in a room that echoes and vibrates her chest[19]. The context provides direct feedback on the rhythm they produce, creating a quick loop. This loop is also discussed in the paper of Krueger (2014), who argues that musical structures can give feedback to the person in a loosely coupled manner; it provides some temporal structure but does not judge or hurt when the person is wrong.

Jikke van Giffen on singing together with a group:

"When everyone is together [in the rhythm], there's no end or beginning in who you are and who the other is"

[19] Teen Crush – JEANS: the stomping nature of the song is noticeable.

Rhythm can stimulate social connection, as shown by the experience of group singing shared by Jikke. She describes a strong emotional reaction to the group being in rhythm. It shows the great potential for rhythm in social bonding and products in general.

The multimodal vibrations have to be intuitively connected to each other, otherwise it causes confusion and discomfort. Jeroen Smit can tell by the movement and sound of the boat if the rowers are on que[20]. If they are not aligned, the boat is not rowing smoothly.

CONCLUSION INTERVIEWS

1. Rhythm can evoke strong emotions
2. Multimodal stimulation can create engaging experiences
3. A direct feedback loop between the rhythm maker and their context is desirable
4. Tactile and auditory vibrations are intuitively connected

Jeroen Smit on multimodal stimuli while steering a rowing boat:

"I can tell if the boat is doing okay by hearing e.g. the oars and feeling the movement of the rowers"

[20] *"In the hall of the mountain king"- London symphony Orchestra: in the movie "The social network" this song is used to communicate the emotions occurring during a (messy) rowing match*

CONCLUSION PART 2

The effect of Rhythmic Entrainment is sensitive to many different factors. To navigate the information available on these factors, the designer is advised to scope their project through rhythmic tasks and resources, as explained in the framework. This also embraces the iterative design process. A designer can research, build, validate and iterate on their design, adding new factors and complexity to the product each iteration.

Keeping it simple, for the user and designer is vital. The benchmark and interviews showed that RE interactions can be confusing to the user when the rhythm is hard to understand or feels out of place. The designer can easily get lost in the amount of information available on the topic, as a lot of the information is case specific or inaccurately uses certain terms.

To develop a sense of intuition to rhythms, it is advised to experience (/play around with) actuators and existing products. For presenting RE, "flat" mediums such as writing can be enriched with examples[21] and visuals. This can also help in understanding the challenges of designing with rhythms.

A few challenges are overarching in every factor: time, sensitivity and interaction. On the micro level, time influences design choices because the user needs to be able to perceive the rhythm and be able to respond to it. On a larger scale, the user might develop skill due to increased usage time, which influences their ability and thus relationship with the artefact. By visualizing a use scenario, time is included in the design process.

The interviews showed that the response to rhythms can be emotional and engaging, especially when the stimulation is multimodal and responsive. The tactile and auditory vibrations do have to be intuitively connected to each other.

A symmetrical interaction between the product and the human is desirable. The interviews highlighted the pleasurable experience of the context creating a loop of direct feedback to the rhythm of the user. However, products are often not capable of responding to the user. The next part aims to enlarge the practical knowledge about responsive rhythms, so designers can create responsive rhythmic products soon.

[21] San francisco – Maxime le Forestier. A song that evokes strong feelings of awe and nostalgia for me personally, describing it with "flowy vocals, a sweet guitar tab and beautiful lyrics" does not do it justice.

RHYTHMIC ENTRAINMENT 4 DESIGN

Working iteratively helps managing the large amount of factors and the interaction between them.

Scoping the design at the start helps in finding the correct and relevant information.

Too much information causes confusion. Keep it simple for the user and designer.

Interacting with Rhythmic products and actuators helps to better understand the design challenges and importance of intuition.

Time plays a big role in Rhythmic Entrainment, it influences nearly all aspects of the design.

Rhythm can evoke strong emotional responses and engaging experiences. However, it is case specific.

Symmetrical RE interactions are valuable, but existing products do not respond to the Rhythm of the user.

03

RESPONSIVE RHYTHMIC PRODUCTS

INTRO

Going back to the pendulum clock and definition of Rhythmic Entrainment; [1] The starting rhythm of both agents should not differ too much. [2] The agents should be coupled loosely. [3] The agents can also differ in their influence on each other (symmetrical or asymmetrical). These rules for RE show that the interaction between the agents is important, this was also emphasized by the interview results. However, the benchmark showed that current rhythmic product interactions are often asymmetrical: the human responds to the product but the product does not respond to the human.

To stimulate the development of symmetrical rhythmic products, this part will further *explore and expand the existent knowledge on rhythmic products that (in some way) adjust their rhythm to the user.*

This section starts with literature research into already existent research cases of symmetrical rhythmic interactions. It also contains a Research through Design case in collaboration with Glimp. This case can serve as inspiration for Rhythmic Entrainment for Design and it can be a starting point for further research, as it takes a more practical approach to the theory. The recommendations that inspire the concept can help Glimp in becoming a responsive rhythmic product.

RESPONSIVENESS IN PRODUCTS

For this section, responsive refers to:

an artefact that is able to adjust the output rhythm by analyzing user input with sensors and data, to facilitate successful Rhythmic

With this definition, a few examples can be found in research; audio that adjusts its tempo to the walking gait of Parkinson patients[22] (Cochen De Cock et al., 2021), assisted breathing through deep touch pressure (Jung et al., 2021) and getting 4 people to tap in synchrony through a "Groove enhancement machine" (Fink et al., 2022). These researches show that in certain circumstances, people enjoy the process of entrainment when the rhythm/artefact responds to them.

From the interview cases and prior research, design factors of responsiveness in rhythmic products can be distinguished. However, some decisions were made to scope the information. [1] The human sets the rhythmic goal they want to achieve and the artefact helps in reaching that goal. An artefact with opposite or unclear goals can be ethically questionable due to the strong influence rhythm has on humans (e.g. the subconscious tapping along to the rhythm). [2] The artefact is loosely coupled to the user, this means the movement and free will of the human is not compromised by the artefact. The assisted breathing vest from Jung et al. (2021) squeezed the user into the right rhythm, which is interesting but can't be considered rhythmic entrainment.

[22] *Schöne Stunden Mit Musik – Musikkapelle Tobadill: A very cheerful marching beat, it surely influences the cadence.*

The factors influencing responsive rhythms are:

1. Input speed: *how often is the human input measured?*
2. Updating speed: *how often does the rhythm change due to the input of the human?*
3. Input type: *is the measured input directly related to the rhythm that is influenced by the artefact?*

Input and updating speed can differ between: none, continuous (measuring/adjusting each cycle) and occasional (only on programmed moments during the task, e.g. at the start). The data type can be direct; for example using the cadence of a shoe sensor to assess the running cadence tempo. In some cases, a direct measurement is not feasible. Indirect input can be considered. For example: using heartrate as an input to estimate (with data and research) the expected walking pace when shoe sensors are out of scope.

With these factors, a few levels of responsiveness have been defined, as shown in figure 11.

In the tapping task from Fink et al. (2022) a real time responsive setting (to a certain level) resulted in better performance and a more enjoyable entrainment process. The interviews also suggest a continuous loop of input and changed output. For this reason, it is assumed that increased responsiveness increases the comfort and correctness of the entrainment task. The rhythmic task and resources available in the context of the RE product determine which level is feasible and desirable. The next chapter will elaborate on the design tensions that influence the selection of a level of responsiveness.

NAME	DESCRIPTION (ARTEFACT..)	INPUT	UPDATE	ANALOGY	RESEARCH
Asymmetric	presents goal Rhythm	None	None	Child keeping up with walking pace of busy mother	Section: Benchmark and (Ghandeharioun & Picard, 2017; Jung et al., 2021; Thaut et al., 1998)
Preference	human can communicate during the task if the goal Rhythm is not comfortable and artefact can adjust to this	Occasional Indirect	Occasional	Clicking the tempo down button on the treadmill	Section: Benchmark
Configuration	creates Rhythmic sequence based on a short duration of user info, beginning with the human starting rhythm and slowly moving towards the goal	Occasional Indirect or Direct	At start	Coach adjusting training because the team had a tough match	Benchmark (Bood et al., 2013)
Correcting	measures user values during the task and activates (notifies) when the values are outside of an acceptable range	Continuous Direct	Occasional	Coach seeing poor execution from student, assigning short exercise to improve	(Ghandeharioun & Picard, 2017)
Real time	measures user rhythm and adjusts the playing rhythm to that rhythm during the task, while aiming for the goal rhythm	Continuous Direct	Real time continuous	DJ adjusting the tempo of the music to the excitement of its crowd	(Cochen De Cock et al., 2021; Fink et al., 2022; Jung et al., 2021)

Figure 11: Levels of Responsiveness with their factors

RESEARCH THROUGH DESIGN

The goal of Research through Design (RtD) is 2-part: [1] presenting new knowledge [2] creating prototypes (Stappers et al., 2019). This section aims to create new knowledge on responsive rhythms, through the practical (prototyping driven) lens of a design case for Glimp: *How to make Glimp responsive to the breathing rhythm of the user?*

Some information about Glimp is presented, together with the design case and challenges based on the desirability, feasibility and viability

The process of building the prototype will illuminate some of the challenges in developing responsive rhythmic products. This information will be used to create recommendations and a concept for Glimp. This concept (and the diary of creating it) can serve as a design case for Rhythmic Entrainment for Design.

GLIMP

The goal of Glimp is to teach people the habit of using their breath as a tool for e.g. reducing stress, fatigue and sleeping issues, by providing daily breathing exercises. Glimp uses handheld vibrating "Pebbles", bio data from the user and app with supporting audio. The vibration pattern of the pebbles indicate the breathing rhythm of the exercise; when the left pebble vibrates, the person inhales, when the right pebble vibrates, the person exhales. Using vibrations on the hands to communicate the rhythm helps the person to be more "in their body". It also fills their hands (so no other activities can be done) and provides a measuring point for the biodata.

The exercises are different each day. For the resonant breathing exercises, the duration of the in and out breath are symmetrical (e.g. 4,5-4,5s). Other patterns also stimulate the user to hold their breath, e.g. "Box breath" which has a 4s pause between in and out, as shown in figure 12.

Breathing tempo is a popular topic of rhythmic products (see: RE cases), with each product having a different manner to output the tempo. Glimp uses tactile vibrations in the hands to create an embodied experience and it wants to use the user data to adjust the breathing exercises to the user. Their embodied approach and goals of being adaptive to the user makes this case interesting for the remainder of this thesis.

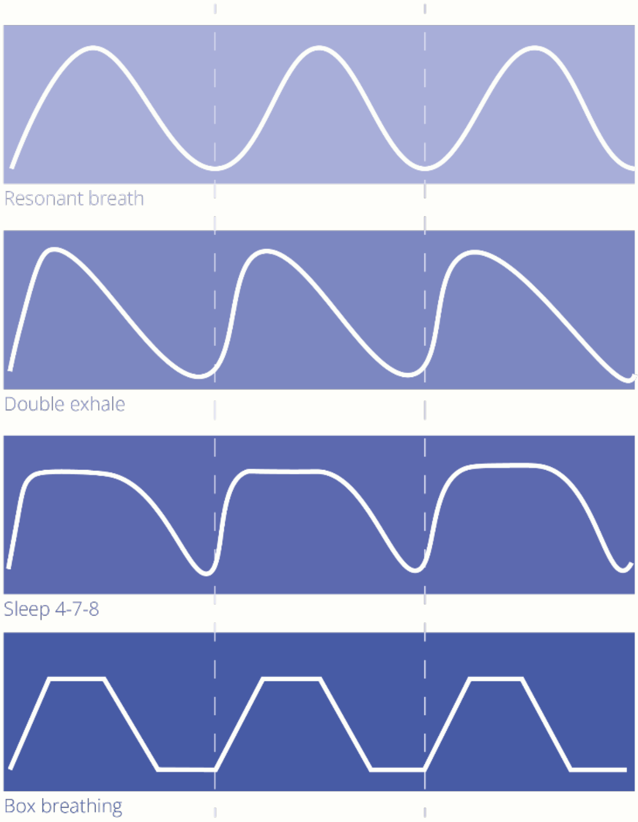


Figure 12: Breathing exercise Rhythms

Case

When a person starts the breathing exercise, their breathing rhythm likely is not the same as the rhythm of the exercise. The main problem from this case is illustrated in fig. 13. If Glimp is able to start the breathing exercise with the rhythm of the user, the process will be more comfortable, the case problem can be described as:

How to make Glimp responsive to the breathing rhythm of the user?

The challenges for this case can be divided into 3 sections: desirability, feasibility and viability. In appendix E, the additional information collected about breathing is provided.

Desirability

- Responsive rhythms can generate strong positive emotions (Fink et al., 2022; Jung et al., 2021; Krueger, 2011)
- The ratio between the inhale and exhale have an effect on relaxation[23] (Cappo & Holmes, 1984; Strauss-Blasche et al., 2000). See figure 12.
- Breathing rhythm can differ per person: each phase can have a different duration (Wheatly, 2018).

With the remaining question:

Does adjusting to tempo differ from adjusting to rhythm in the comfort the user?

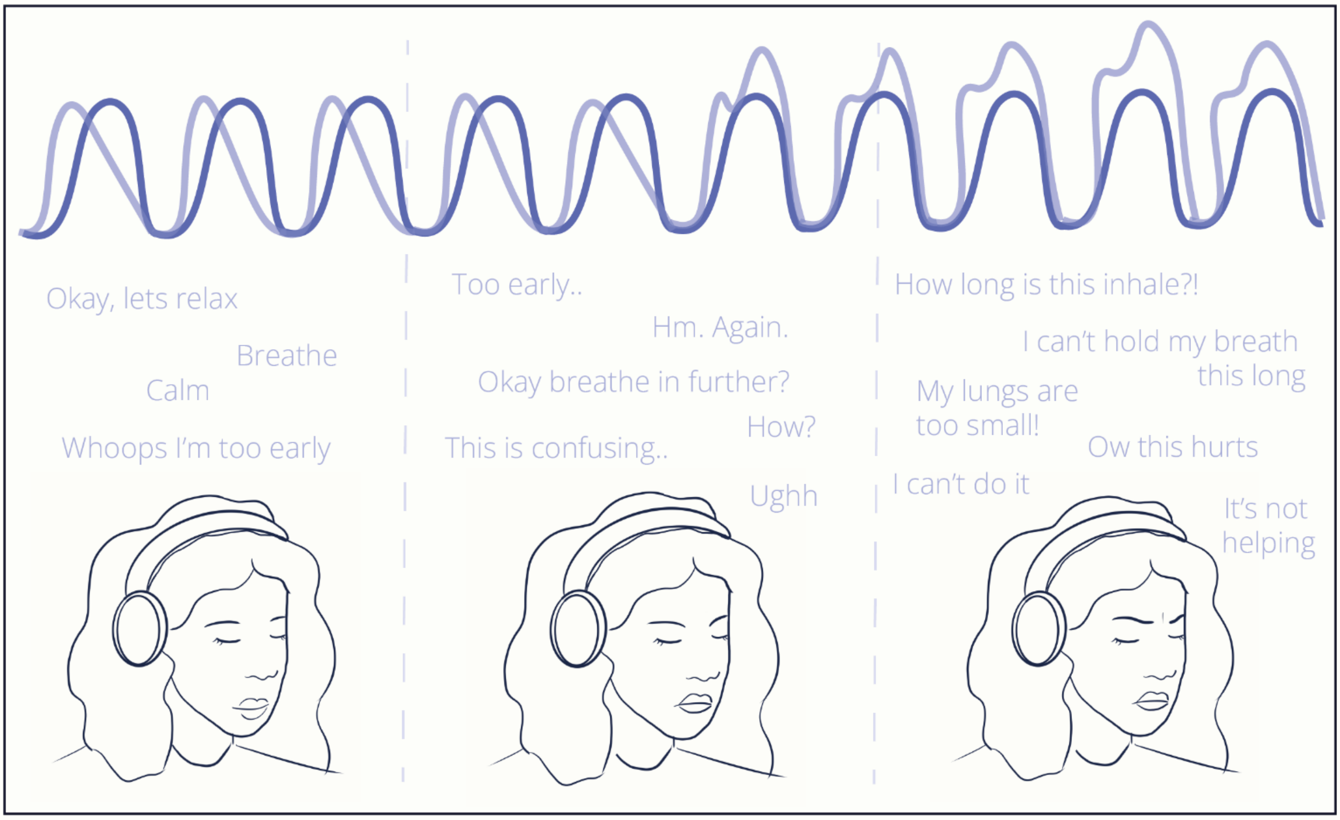


Figure 13: Case problem of Glimp

[23] Maduea – Soma breath: Music that through rhythm and melody stimulates a relaxing breathing pattern

Feasibility

- Glimp was founded recently, their human, data and monetary assets might not be as broad. However, their connection to the Technical University of Delft is valuable in reaching their goals.
- The currently available resources of Glimp for measuring user variables are limited to: a smartphone, PPG sensor data, accelerometer data and user data from previous sessions.
- The breathing tempo measured with PPG can only be calculated after the session is done.

With the remaining question:

Is it possible to build a system that is useable outside of a lab setting?

Viability

- Unique selling point: Glimp can be the 1st responsive breathing tool in the market, according to product cases and benchmark analysis.
- Collecting large amounts of data about breath outside of a lab setting is valuable (Charlton et al., 2018).
- Development of accurate tempo calculations using PPG have been marginal and slow (Iqbal et al., 2022), investing into the development can be risky.

With the remaining questions:

How valuable is responsiveness in breathing exercises?

Does it improve user experience enough to invest time & money into the development?

USER RESEARCH

Looking at the desirability, feasibility and viability of making Glimp responsive to the user breath, one question needs to be answered first: *Does an increased level of responsiveness increase the user comfort during the entrainment process?*

It is expected that Glimp can be responsive by *understanding the limitations of the current hardware and being creative in measuring the user data.* For the current situation a *configuration* level responsiveness appears realistic, but a *real time* responsive mechanism could be interesting in supporting the users as well. Therefor the user test will compare the responsive levels of "configuration" to "real time" on the experienced comfort and performance.

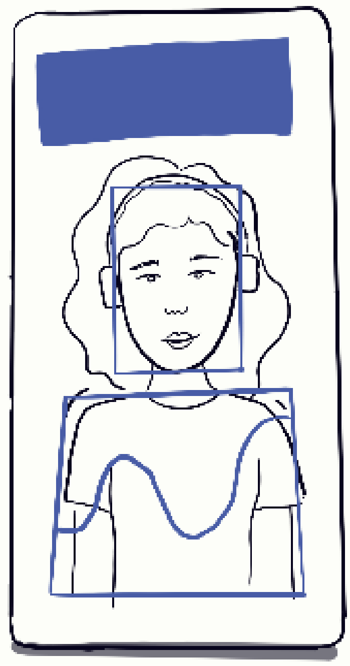


Figure 14: The Google Fit app shows the breathing rhythm on the chest and gives an average Tempo at the end

METHOD

Prototyping

The prototypes were built in MAX/Msp, this is a visual programming software often used for music making through MIDI signals. A baseline measurement of the user breathing tempo is done with the Google Fit app as shown in figure 9.. It uses the phone camera to analyze the shoulder, chest and throat movements, displaying the rhythm as a graph after 2-3 seconds and the average tempo after 25 seconds (Deo Mehta & Sharma, 2023). The baseline user tempo is filled in by the researcher into the prototype. The tempo for the upcoming sound is determined by using the importance score for the tempo of the human and the goal:

$$Tempo,n + 1 = Th,n * Ih,n + Tg,n * Ig,n$$

With:

$$Ih,n + Is,n = 1$$

This score can change over the duration of the task, being more goal oriented towards the end. Figure 15 shows what the importance looked like for both of the task types. For the configuration task, only the baseline measurement tempo is used for determining the next tempo. In the real time task, the average user tempo of the last 4 cycles is used to update the tempo of the sound.

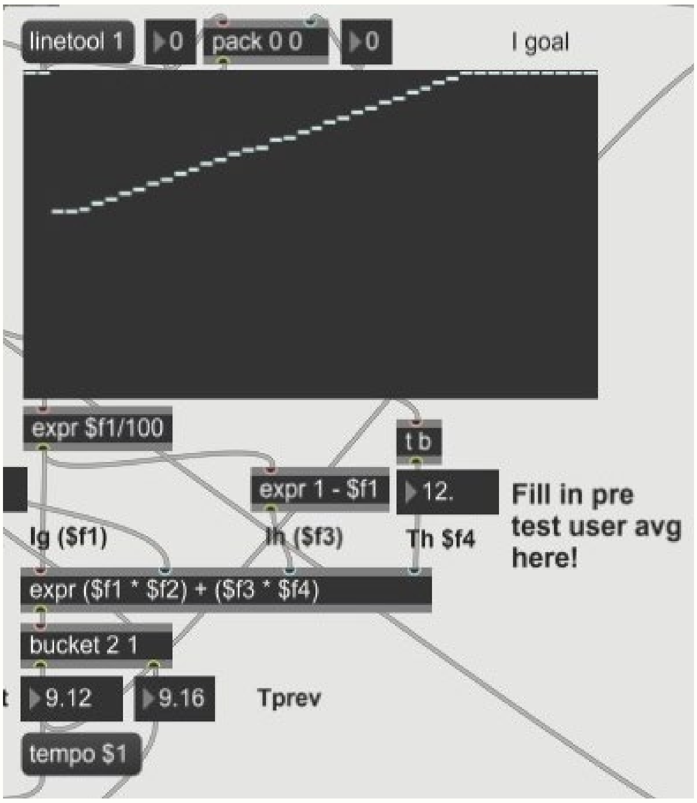


Figure 15: How the importance factor changed during the Configuration task

The breathing tempo of the user was measured by the researcher pressing a button each time the participant had exhaled entirely. For both prototypes, the program exported these tapping times and the duration of the sound of the same breath cycle. This data was later analyzed in Microsoft Excel.

User testing

Participants were randomly selected and informed about the benefits of slow breathing. The breathing rhythm was displayed via a headset and they were seated in a private space with the researcher.

The sound consisted of 2 tones that reduced their volume towards the end of the phase; a 164Hz tone to indicate in and a 82Hz tone to indicate out. At the start of the research, they were given a short demo of the sounds, checking if they were able to hear the entire sound. Prior to each breathing exercise, their baseline breathing tempo was measured using Google fit. Each participant experienced both tasks, in a random order. After the task, the participant fills in a few questions regarding their experience of the breathing exercise. To have some time between the two exercises, the users filled in some of their background information regarding skill, motivation and focus . The baseline measurement was executed again and the 2nd exercise is executed. For this exercise the user also answered some questions regarding their experience. A short interview followed to discuss their overall experience and get more in depth information about their skill, motivation and focus.

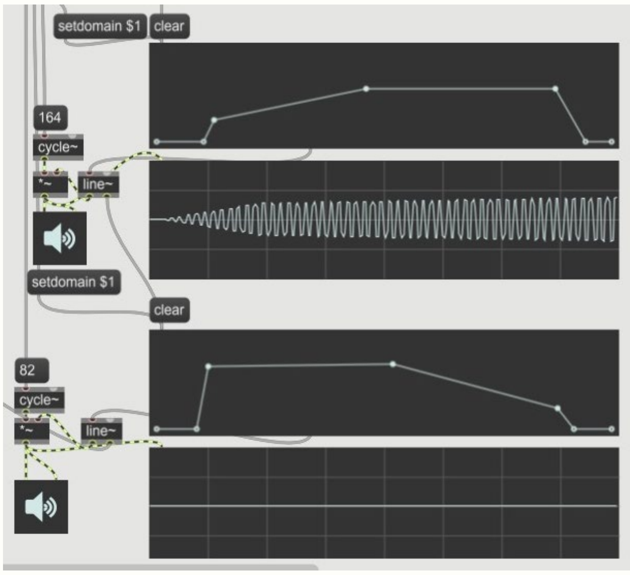


Figure 16: The different tones with their intensity in Max/Msp

Processing data

Merely looking at the experience of the participants is not enough to determine the value of the task type. A participant might enjoy the task, but barely achieve the goal. Therefor the experience score (1="uncomfortable", 7="comfortable") and the comfort time (1="uncomfortable all of the time", 7="never uncomfortable") are corrected with the performance of the participant, using:

$$\begin{aligned} &Corrected\ Comfort \\ &\qquad = 0{,}4 * Experience\ score + 0{,}4 \\ &\qquad * comfortable\ time + 0{,}2 \\ &\qquad * performance\ score \end{aligned}$$

The performance is less important in this process as the goal is to study the comfort of the user.

The performance of each of the participants was calculated using:

$$P = (Ds, goal - Dh, end) * \frac{(Dh, end - Dh, start)}{(Dh, goal - Dh, start)}$$

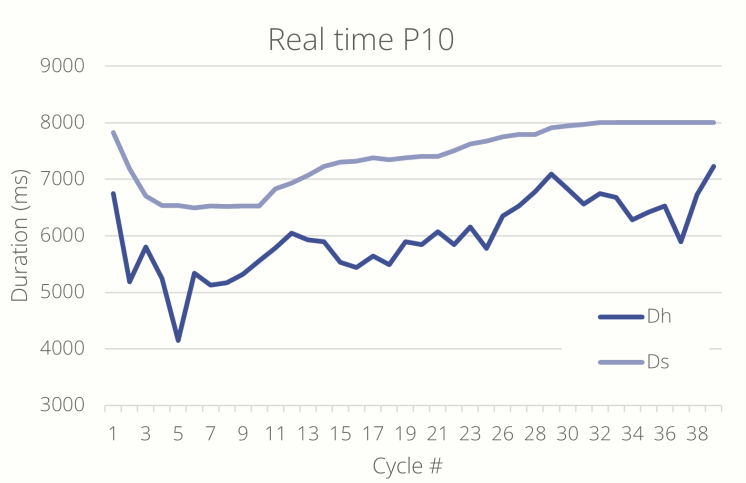
Measuring the difference between the goal duration and their ending duration, weighted by the challenge they faced. This data is translated into a ranking from a 1= bad performance, to 7= great performance. Appendix F has a more elaborate explanation of this formula.

The information from the interviews is used to further elaborate and explain some of the outcomes of the research.

RESULTS

Usertest data

The research was conducted with 10 participants between the ages of 20-28. Their performance results and subjective experiences on different topics are displayed.

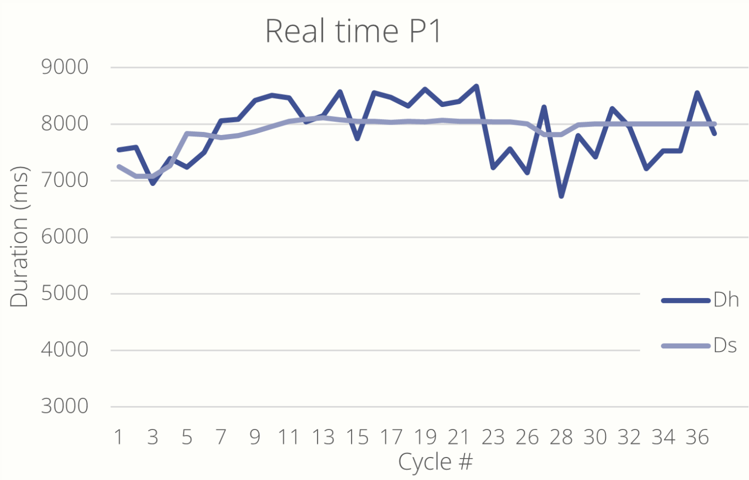


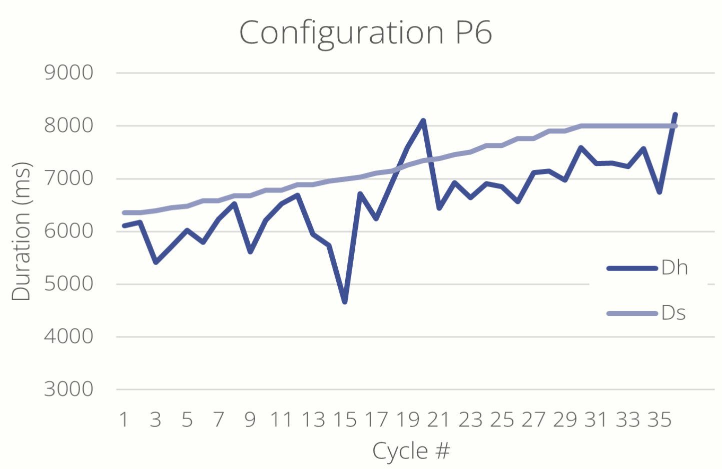
"I don't care about being exactly in the rhythm with the sound, I don't want to force my breath"

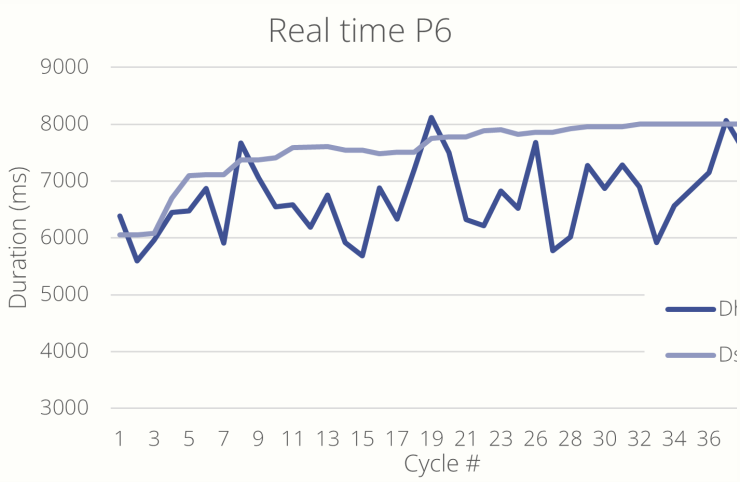
Participant 10 (labelled as "little relevant skill"), on the question: "How motivated were you to perform the exercise exactly right?"

"If inhaling took too long I knew there was still some space if I steered my breath towards my stomach. I did this before with the Wim Hoff method"

Participant 1 (labelled as "Skilled") on the question: "How does your skill in breathing relate to this exercise?"







" [real time] required more attention from me, [configuration] felt more natural and easy"

Participant 6 (labelled as "little relevant skill"), on the question: "How focused were you during each of the tasks?"

"I really wanted to be in rhythm with the sound but when my lungs are full, they're full, I can't add more air if there's no space in my lungs left"

Participant 8 (labelled as "no relevant skills"), on the question: "Did you ever feel uncomfortable during one of the tasks"

"I don't like how the exercises tell you what to do, in meditation it is much more loose, guiding a bit but leaving the control to the person"

Participant 5 (labeled as "moderately skilled"), on the question "How does your skill in breathing relate to this exercise?

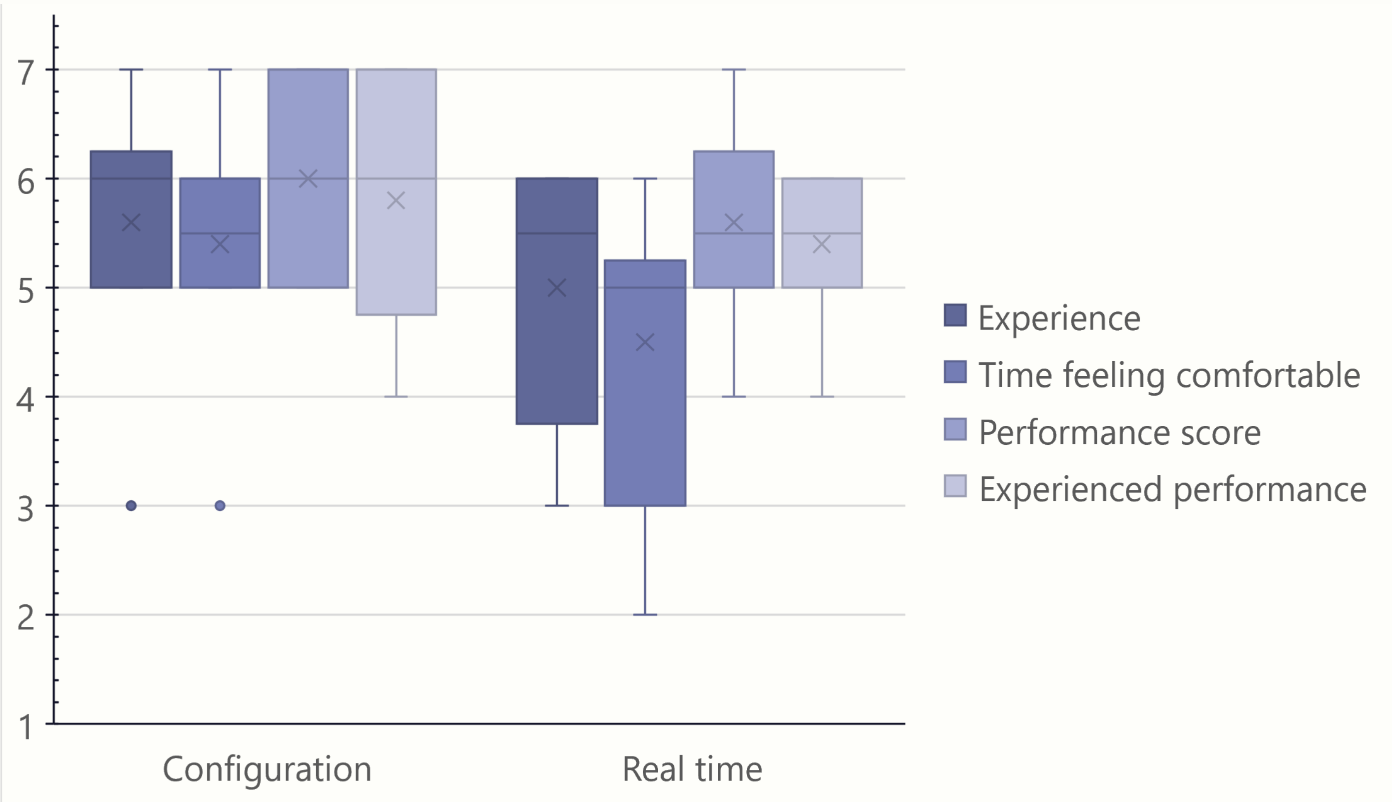


Fig. : Divide of corrected comfort score parameters of participants (Experience was rated 1="Uncomfortable" and 7= "Comfortable". Time feeling comfortable was rated 1= "never", 7="all of the time". Performance score: 1= "poor performance" 7= "outstanding performance". Experienced performance: 1= "followed the tempo poorly", 7="followed the tempo perfectly")

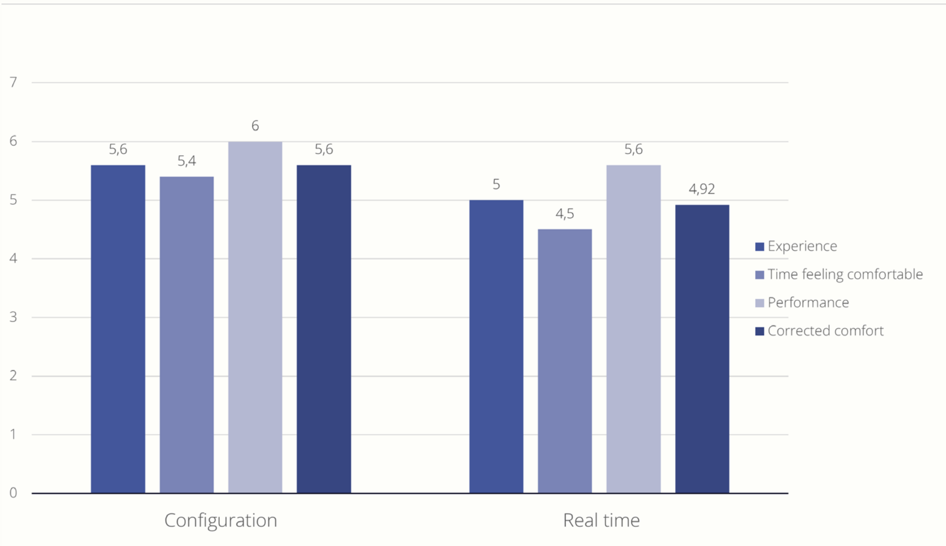
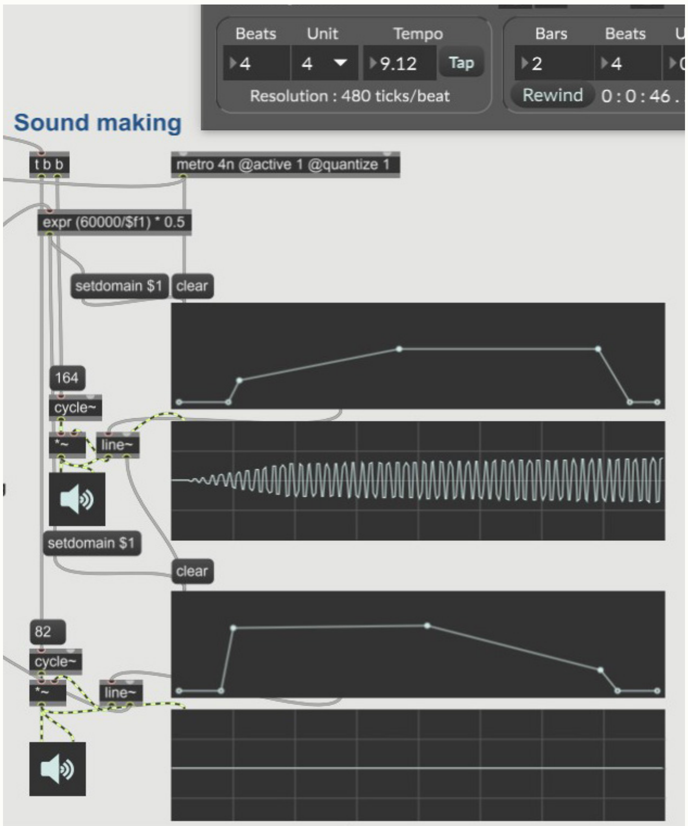


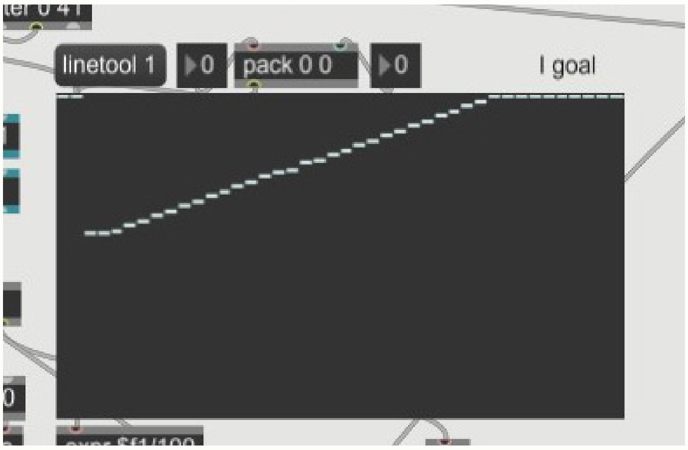
Fig. : The average scores of each of the parameters for corrected comfort

Prototype

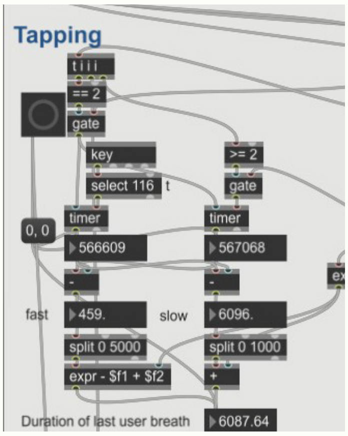
Any notes on the prototyping were collected in the RtD diary in appendix F. Each prototype screenshot is accompanied with notes from the diary.



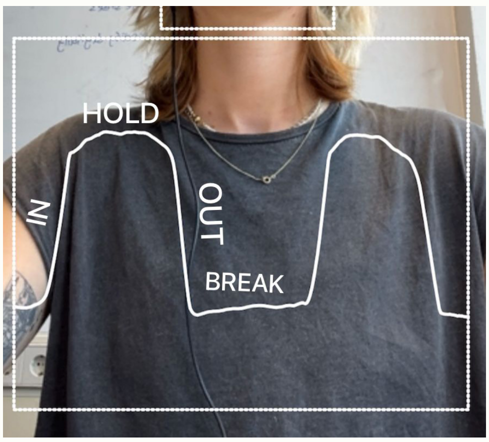
At which intensity is the sound no longer audible? And how much time between the two sounds? For a 1:1 rhythm ratio?



Importance should never be less than 0,5 at the start. Otherwise it's confusing.

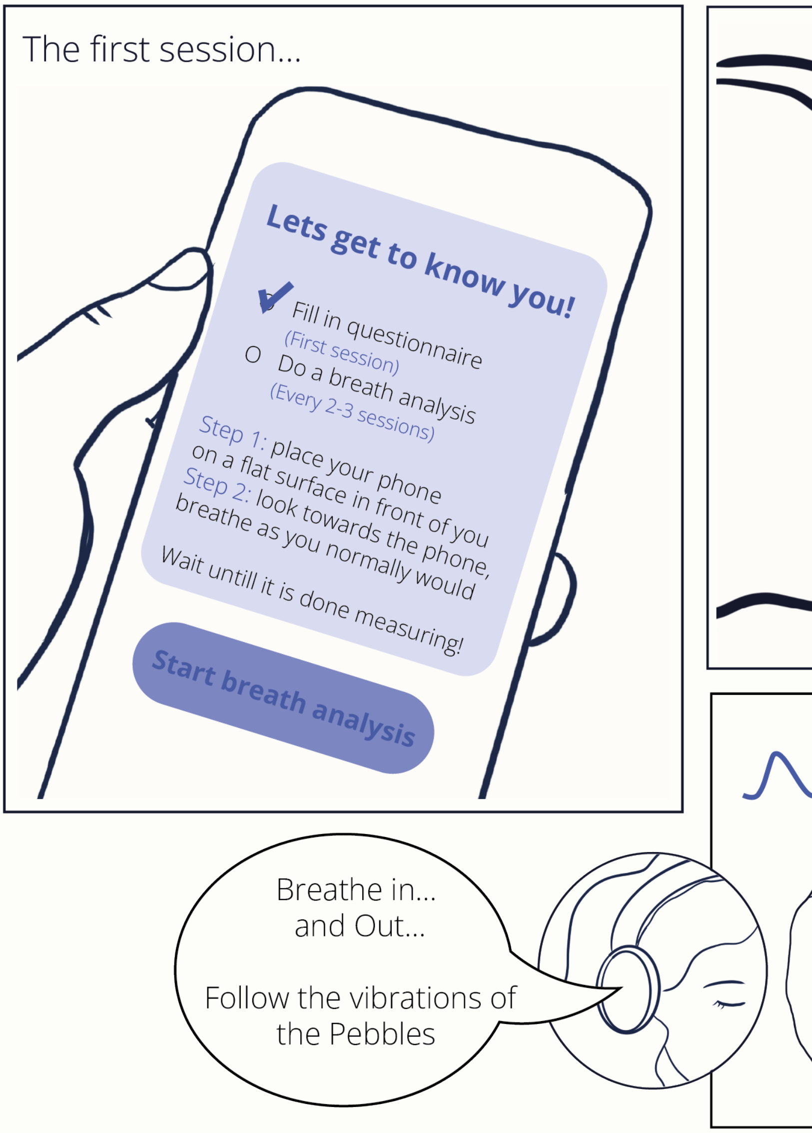


Patcher from forum did not use the right time calculation. Calculating the time between taps results in period correction, not phase.

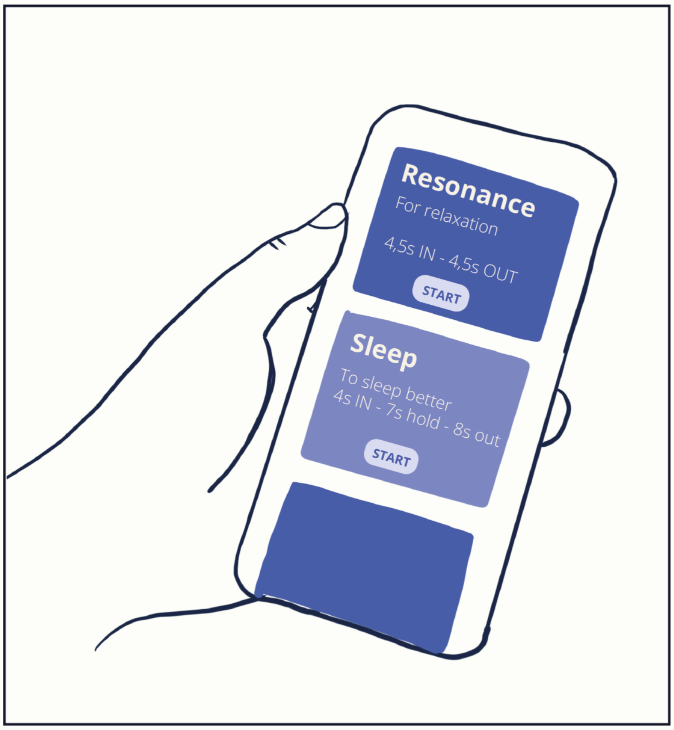


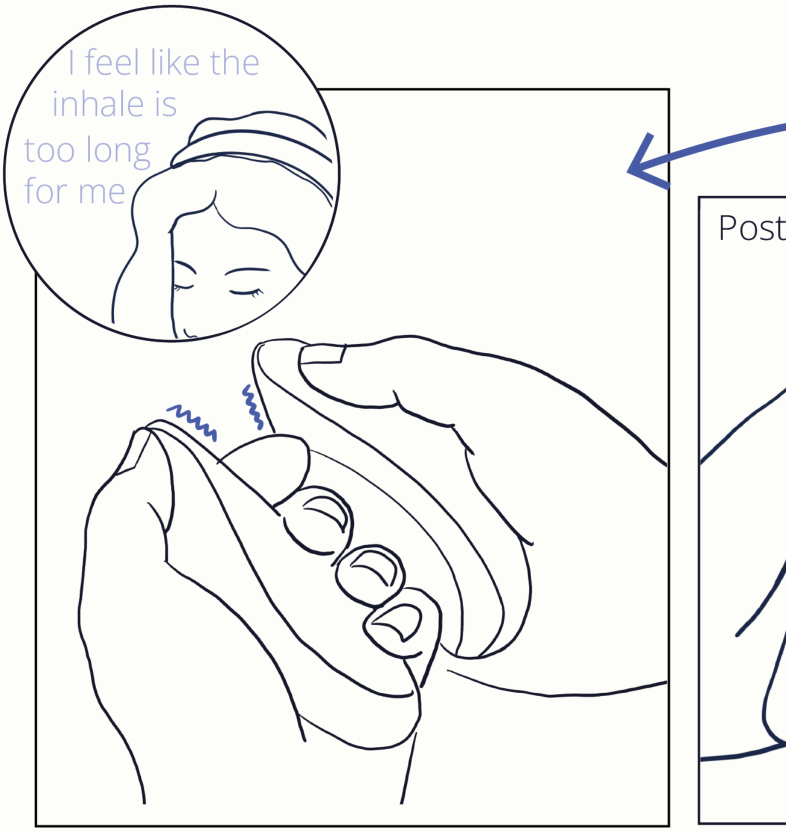
Can I make my own visual breath analysis tool? Which training data?

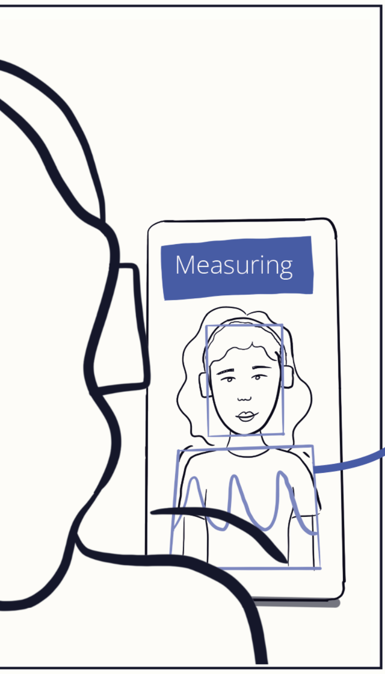
SKILL LEVEL: 1



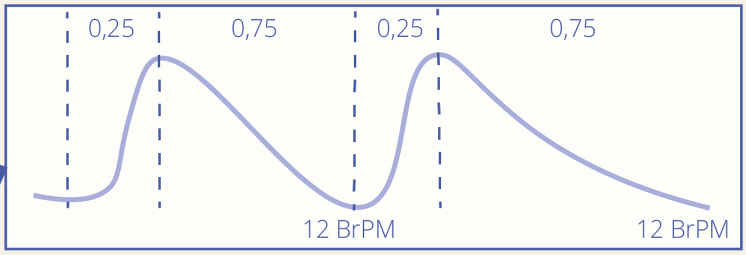
SKILL LEVEL: 2







USER DATA



Questionnaire results:

Experience in:
Yoga: 0/10
Breathing: 1/10

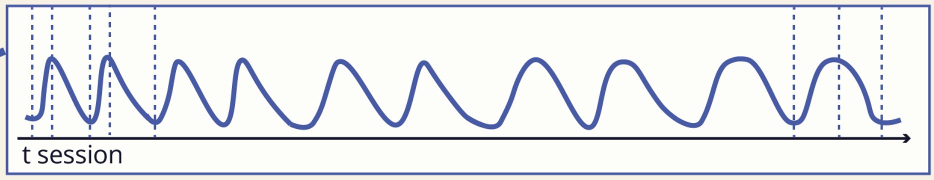
UserR: IN: 0,25 OUT: 0,75 **UserT:** 12 BrPM **Skill:** Low

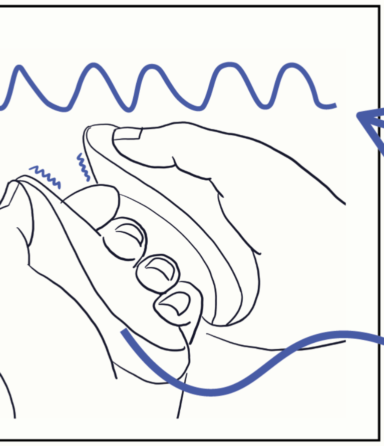
OUTPUT

START:
Strictness: Low
Tempo: 40% * UserT + 60% GoalT
Rhythm: 100% of UserR

ENDING:
Strictness: Low
Tempo: 100% GoalT
Rhythm: 100% GoalR

Session plan





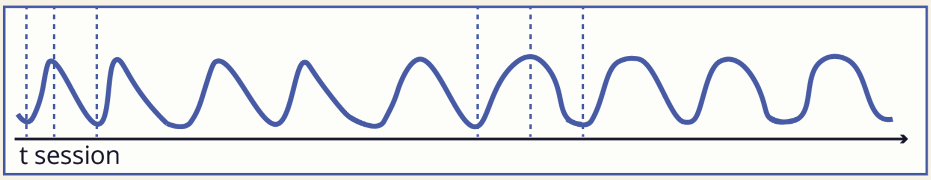
POST SESSION USER DATA

PPG SENSOR DATA: Average UserT during session

PRIOR USER DATA

Average UserR: IN: 0,15 OUT: 0,85
Average UserT: 12 BrPM (N>15)
Skill: Mid

Session plan



POST SESSION USER DATA

PPG SENSOR DATA: Average UserT during session
USER OPINION: Estimation of their breathing Rhythm

DISCUSSION

Does an increased level of responsiveness increase the user comfort during the entrainment process?

When comparing real time responsiveness to configuration, the increased responsiveness of real time does not increase the user comfort during the entrainment process. Based on the corrected comfort score and the interviews it can be said that the difference between the two systems was noticeable and participants preferred the configuration task.

In addition, participants performed better and were also more positive about their performance. They were able to estimate their performance quite accurately. When asked if they would use a "tempo up/down" button during the task, 4 participants could point out moments in the exercise when they would have used it.

Motivation and skill/prior knowledge influenced their experience as well. Participant 10 clearly stated they care more about their comfort, which resulted in a lower performance. Participants that practiced meditation, yoga or breathing exercises reported they were able to steer their breath and thus avoid discomfort.

When the participants experienced discomfort, 6/10 times they mentioned the breathing rhythm of the prototypes. The sound of the prototype indicated the rhythm of the breath, but the prototype only measured the user tempo. Measuring the duration of the entire breath but creating 1:1 inhale/exhale ratio for the output sound[24] leaves out any user that does not have that ratio. However, while tapping along to the breath of the participant, the researcher noticed that each participant had a different breathing rhythm.

[24] Johny says stay cool – Babe Rainbow: the song uses "Breathe" in and "Breathe out" in a (way too) funky manner, causing confusing breathing patterns.

Limitations to the prototypes

The prototypes had some limitations due to the measurement method, tapping along to the movement of the chest area of the participant is challenging. The researcher practiced with a physiotherapist to learn how to "read" the breath of a person. To avoid any tapping related accidents, an error range was determined and the real time prototype only used the average tempo of 4 cycles that were within that range.

Regarding character of the vibration; at the beginning of the session, the user tempo was too influential. Based on the responsive tapping task research of Fink et al. (2023) the user tempo was 40% of the starting tempo of the task. However, when doing a breathing exercise, participants expected a slow tempo, they were often confused when they were introduced to a tempo similar to their baseline measurement.

Finally, the real time prototype might have updated too often, which caused confusion. For future research it is recommended to update the tempo only every 5-6 cycles.

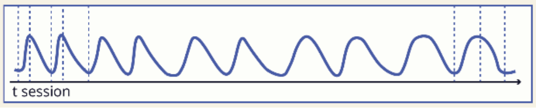
CONCLUSION

Predictability

START:
Strictness: Low
Tempo: 40% * UserT + 60% GoalT
Rhythm: 100% of UserR

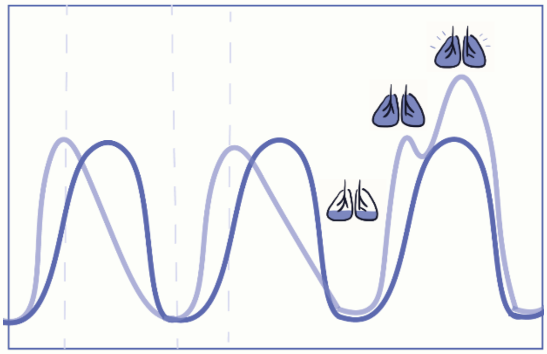
ENDING:
Strictness: Low
Tempo: 100% GoalT
Rhythm: 100% GoalR

Session plan



Going back to the theory of RE, it makes sense that real time responsiveness to breath was considered confusing. Due to the delay of the data, the real time prototype updated 1 cycle after the latest user data was gathered, while still playing the sound at the old tempo. **Users could not predict the next rhythmic pulse and could thus not entrain to it**[25], requiring a lot of focus to execute the task right. The configuration prototype changed its tempo more gradually, making it predictable. The concept therefore proposes a configuration approach, with the adjustment strictness (amount of cycles before reaching goal tempo) matching the skill level of the user.

Breathing Rhythm vs. Tempo



Breathing exercises should consider the breathing rhythm, not just the tempo. When asked if they ever felt uncomfortable during one of the tasks, 6/10 participants mentioned the timing of the phases of the breath. They mentioned forcing their breath to reach the duration of the sound, which meant they had to extend their chest too much or hold their breath for too long. The prototypes only adjusted to the tempo, but indicated different phases of the breath, assuming every person has a symmetrical breathing rhythm. The researcher noticed that, unlike the common conception of a perfectly symmetrical wave, **the breathing rhythm of each participant was different**. Therefore the concept also adjusts to the rhythm of the user that is measured or predicted prior to the session.

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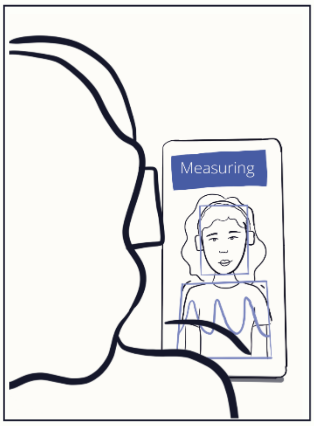
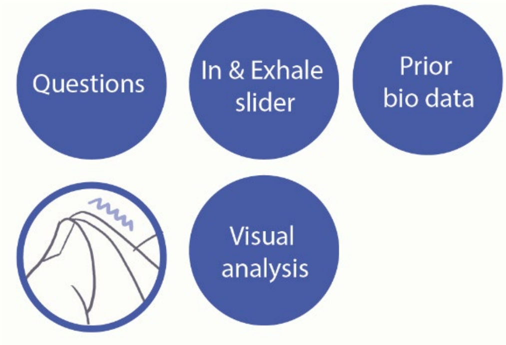
[25] *Love U like the sun in june – Ryan Scott: the consistent bassline makes the rhythm easy to follow.*

Sensing Breath



Taking the current resources of Glimp into account, the prototype did not use any invasive (on the body) measurement methods. The PPG sensor was not used because as of today, these sensors are not able to accurately and quickly calculate the breathing tempo (Iqbal et al., 2022). **Measuring breathing rhythm remains the biggest challenge of this case,** but a visual analysis shows great potential. Participants enjoyed using Google fit and seeing their own breathing rhythm prior to the task can help them visualize the breathing pattern during the task (Chittaro & Sioni, 2014). The concept uses a visual analysis every 2-3 sessions during the 1st month of using Glimp. The user can benefit from seeing their breath and at the start, and prior data to predict their breathing pattern isn't available yet.

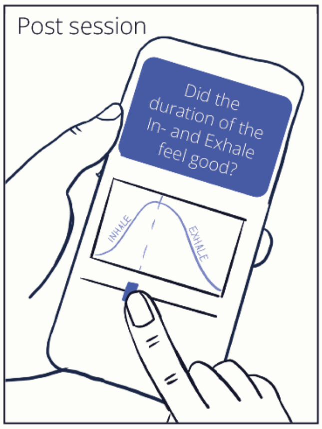
Diverse data

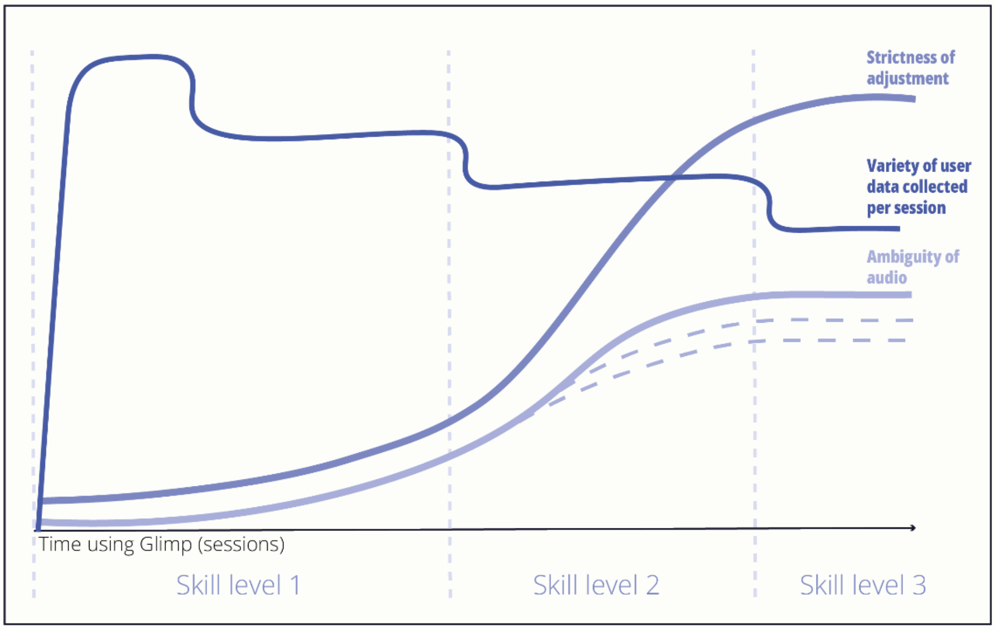


To bridge the lack of information about the breathing rhythm of the user, it is recommended to create a **variety of data sources on the user.** The google fit measurement helped a lot in assessing their performance and doing interviews at the end of the sessions made the data more understandable. To improve current prediction models for breath, data is needed first. The concept uses multiple methods of gathering data.

Awareness

Participants were aware of their performance and could communicate it clearly when they felt discomfort. Thus, simply asking the user afterwards, especially if they are more skilled can provide a simple but effective solution.





Participants who practiced meditation stated they prefer a more “loose” approach to breathing directions[26]. Leaving more room for free interpretation of the rhythm, so the user does not feel judged or failing when they do not breathe entirely in rhythm. Participants with low skill were often confused by the sound and struggled more with their breathing rhythm.

skill can be interesting. At the start, the soundscape has a clear rhythm with a voiceover indicating inhale and exhale. When the skill improves, the soundscape can become more music-like, like the music used for SOMA breath. Users can eventually choose which elements of the soundscape they want to activate.

[26] *5 minute guided meditation – Headspace: starts with some relaxing breathing instructions without giving a time indication*

CONCLUSION PART 3

Part 3 aimed to *explore and extend knowledge on rhythmic artefacts that adjust their rhythm to the user*.

From literature, factors that determine the degree of responsiveness can be distinguished and a few levels were described. The research shows that responsive rhythmic artefacts are valuable for design; creating strong positive emotions in participants.

To further explore the challenges and opportunities in responsive rhythmic artefacts, a Research through Design case was executed with a design problem from Glimp. A user test with 2 prototypes for the responsive levels resulted in recommendations that inspired a concept for Glimp. The concept adopts a "configuration" level of responsiveness to the breathing rhythm of the user, in combination with a variety of data measurements of the user and a soundscape that adjusts to their skill level.

The description of the case can inspire designers who want to learn more about Rhythmic Entrainment, as it is part of the RE4Design framework. The case displays the interplay of factors and how to design with them.

The case also gives insights into the process of designing with rhythm. The information from part 1 and 2 were not enough to fully execute the design process, more information was gathered about breath specifically. By defining the rhythmic task, it was possible to look at the available information in a critical manner. In this case, the difference between tempo and rhythm has been an issue. More often than not, (breath) researchers mistook rhythm for tempo. Which is disturbing, considering the importance of breathing rhythm in perceived comfort.

The prototypes show that building responsive rhythmic products is feasible, but timing makes it more challenging than asymmetrical product interactions. Picking the right user data source (input) and aligning the data to send (output) at the right time were the biggest challenges of building the prototype.
The relation (ability, skill and motivation) to the task and the available resources (from the case) for the sensors were relevant as well.

Another noticeable aspect is the ability to transfer the learnings from one responsive system to another system. Systems for high tempo (80-180 BPM) tasks such as tapping can be more responsive (50% of user tempo in (Fink et al., 2022)) to the user than systems aimed at slow (6-20 BPM) tasks such as breathing. Even between the two (nearly identical) prototypes, the graph depicting the importance of the user rhythm did not generate the same perceived character. Large tempo differences and character did not translate between each case, it is unknown if this applies to more aspects of responsiveness levels.

However, this RtD case might not be as representative for all other RE tasks. Breathing rhythm is a challenging and sensitive bodily rhythm. The sensors for measuring breathing rhythm continuously in daily life do not exist and thus no data exists on the occurrence of different types of breathing rhythms, which complicated the prototyping. Humans need to breathe, if participants feel constrained, rushed or confused about the exercise they can feel threatened. This will likely generate stronger negative emotions than to a (non-threatening) tapping task.

RESPONSIVE RHYTHMIC PRODUCTS

Levels of symmetrical (responsive) Rhythmic product interactions have been determined.

Responsive products can be valuable, but too much responsiveness causes confusion. It is likely case specific.

Remain critical in searching case specific information, especially regarding tempo and rhythm.

In responsive systems the timing of in and output of data is challenging and important.

Recommendations for future research (in multiple fields) can be made from the Research through Design case.

An example concept case is presented to inspire designers and reveal some of the challenges of RE4Design.

04

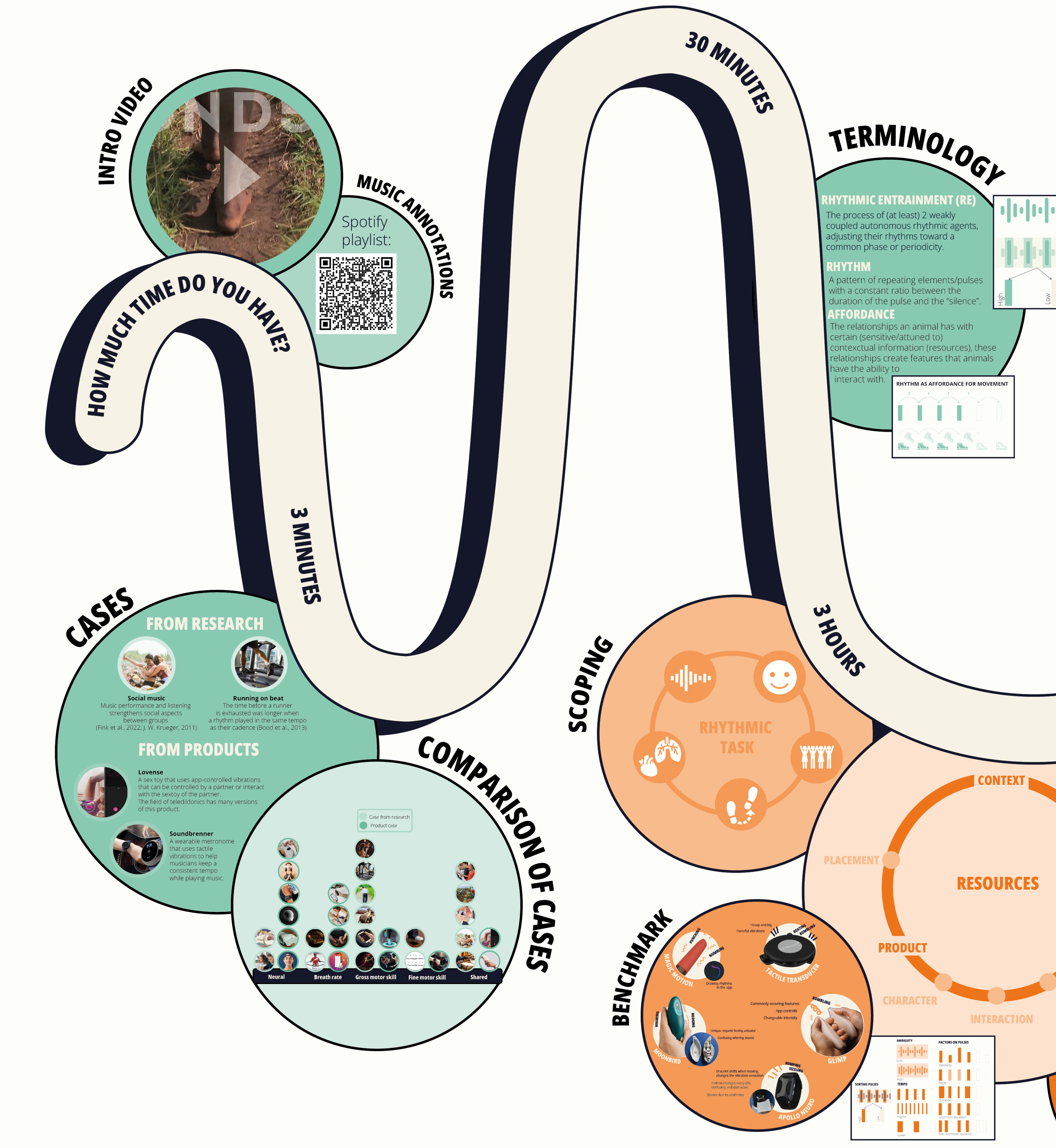
CLOSING

RE4Design:
RHYTHMIC ENTRAINMENT FOR DESIGN FRAMEWORK

HOW TO USE

This framework is built to inform designers about Rhythmic Entrainment. It contains a quick overview of the information that is provided in the accompanying thesis report. The color of each bubble corresponds to the chapter of the thesis where information of that bubble came from. The findings are divided into 7 insights, as seen on the right.

Please inform yourself from left to right.



t.

to

Experiencing RE

Opportunities

Knowledge gathering

Time as a design aspect

Interaction

Particular sensitivity

Keep it simple!

"Rhythmic Entrainment for design"
Frederike Stortelers

RESPONSIVE RHYTHMS

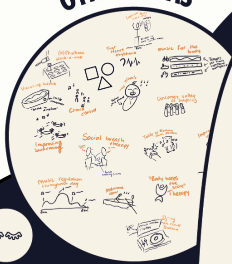
RESPONSIVE:
A product that is able to adjust the output rhythm by analyzing user input with sensors and data.

WHY IS THIS VALUABLE?
Responsive contexts were considered valuable in the interviews and research has shown it can generate strong positive effects. Most products on the market are not responsive.

LEVELS OF RESPONSIVENESS
A few levels were distinguished, which differ in their input speed, output speed and origin of data. More responsiveness is assumed to be beneficial

3 DAYS

OTHER IDEAS



INSIGHTS

Experiencing RE

Opportunities

Knowledge gathering

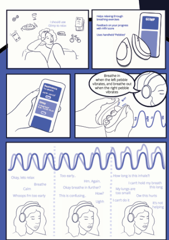
Particular sensitivity

Time as a design aspect

Interaction

3 WEEKS

CASE PROBLEM



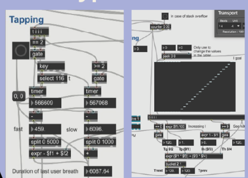
How to make Glimp responsive to the breath of the user?

RTD CASE

What is desirable, feasible & viable?

Does an increased level of responsiveness ("real time" vs. "configuration") increase user comfort?

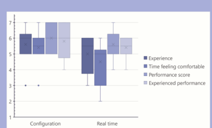
Prototypes



Measuring breathing Rhythm is complicated & data is delayed

Knowledge on character does not translate across types

Usertest

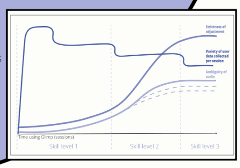


Importance of Rhythm vs Tempo:
"I really wanted to be in rhythm with the sound but when my lungs are full, they're full, I can't add more air if there's no space in my lungs left"

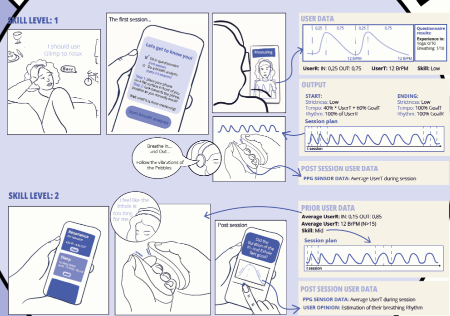
Importance of skill:
"If inhaling took too long I knew there was still some space if I steered my breath towards my stomach. I did this before with the Wim Hoff method"

Conclusion:

The concept adopts a "configuration" level of responsiveness to the breathing rhythm of the user, in combination with a variety of data measurements of the user and a soundscape that adjusts to their skill level.



EXAMPLE CONCEPT



RESOURCES

ATTENTION

SKILL/ PREFERENCE

HUMAN

MOTIVATION

INTERVIEWS

RHYTHM CAN...

Respond via the context
"I want to be close to my crowd so I can feel them stomp to the music, then I know if I'm doing it right."
JEANS (Techno DJ)

Be an engaging social experience
"When everyone is together [in the rhythm], there's no end or beginning in who you are and who the other is"
Jikke van Giffen (Singer)

Be emotional
"I see everyone enjoying the music, I see their emotions and movement, but I do not feel it. I'm outside of it all"
Steve Toet (Hearing disabled)

Be multimodal
"I can tell if the boat is doing okay by hearing e.g. the oars and feeling the movement of the rowers"
Jeroen Smit (Coxswain)

Full (zoomable) version of RE4Design Framework:

DISCUSSION

The main findings of this thesis are:

1. The topic is best understood and explained through experiences
2. Rhythmic Entrainment can provide opportunities in multiple fields and manners.
3. Finding the right information and sorting it makes designing with RE complicated
4. Keep the process simple
5. Time influences nearly every factor of RE
6. The interaction between each factor is important
7. People are sensitive to RE

These findings were generated based on literature research, a product benchmark, interviews with experts and a Research through Design case with a design problem from Glimp. To elaborate, each finding is discussed and related to their preceding research.

Experiencing RE

Opportunities

Knowledge gathering

Time as a design aspect

Interaction

Particular sensitivity

Keeping it simple

EXPERIENCING RE

In part 1, the definition of Rhythmic Entrainment was explored. While researching its value and workings it was noticeable that giving examples is helpful in understanding the topic. These examples can be research cases and products, but even written text can be enriched with analogies, visuals and examples from music and daily life.

In the benchmark test it became clear that being hands on with the products and playing around with the actuators can help in understanding the challenges of designing with RE. In short; provide rich and diverse examples to teach and design with RE.

OPPORTUNITIES IN RE

Existent research, interviews with rhythmic experts and a RtD case show how valuable it can be; it can help us reach our goals with increased comfort and it creates intuitive and engaging interactions. The applications of RE can be broad across industries; entertainment, sports, mental and physical healthcare, sexuality, education, and so on. Current products are mostly aimed at mental health, which leaves a lot of room for novel ideas and applications. Especially the effect on social interactions is relevant today.

There is a gap between the theory and the application, which makes the topic interesting for research as well. Research and Design can both benefit from a collaboration; design gives direction to research, showing which aspects should be studied to generate valuable knowledge. Especially if the research is aimed at application (e.g. in Research through Design), the new knowledge can improve product design. More on this in the chapter “Recommendations”.

GATHERING KNOWLEDGE

One of the main challenges of this thesis was collecting the *right* knowledge and sorting it. Part 1 required proper descriptions of relevant terms for this thesis. Finding practical definitions was complicated because [1] many fields have studied RE, resulting in different meanings. [2] There are many closely related topics (e.g. resonance) that create confusion. [3] The absence of one common definition for important aspects of RE cause incorrect usage of terms, for example; tempo vs. rhythm, pitch vs. frequency, tactile vs. audio vibrations.

Additionally, a lot of information is available, most of it isn't useable for designers. Part 2 sorts basic information for designing with RE by using a framework of (rhythmic) tasks and categorized resources, inspired by the framework from Wilson and Golonka (2013). The designer still has to search additional case specific information.

The RtD case proved that defining the rhythmic task beforehand is helpful in narrowing down the search terms and having critical view on the information.

TEMPORALITY

Time plays a big role in nearly every aspect of RE. In part 1, the perception of rhythm is attributed to our ability to predict the occurrence of a new pulse and rhythm is presented as an affordance for movement in time. This has helped in presenting RE in an understandable manner.

In part 2, time creates design tensions between different aspects of RE context. For example: a running task requires quicker, lighter actuators than a (stationary) breathing task. Additionally, aspect such as skill, attention and motivation can be influenced by time on larger scale. A person using the product for a longer time might increase their skill, decreasing their need for full attention to the task.

In the RtD case, time complicated some of the prototype making. Responsive rhythms are even more dependent of time, there is a delay between processing the input data and outputting the new rhythm.

INTERACTION

The definition of RE emphasizes the importance of the interaction between the two rhythmic agents; they need to be loosely coupled and their influence on each other can differ.
Part 2 shows that design choices can influence multiple aspects of the RE product and that some resources are relational.
The interviews revealed that RE can evoke strong positive emotions and engaging experiences when the interaction between the human and rhythm is symmetrical.

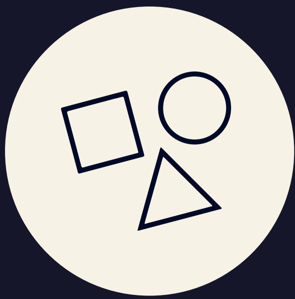
Unfortunately not many products exist that “respond” to the user. Therefore, part 3 set out to research and develop applicable knowledge on the topic of responsive rhythms. Which showed that it is valuable and feasible. However, it is case specific, if the product responds too much to the human it becomes confusing.

PARTICULAR SENSITIVITY

In the definition of rhythm, the individual ability to perceive the rhythmic structure highlights the particular nature of RE. Being able to detect the rhythmic structure in a (chaotic) sonic context can depend on personal factors such as ability and motivation.

This insight is also connected to knowledge gathering, as researchers are prone to generalize their findings without considering the context of their research. If the design case isn’t closely related to the research, the findings might not be applicable due to the particularity of the context. Designers are advised to remain critical and take context specific knowledge as an inspiration, while studying their specific case for vibrations and rhythms that are intuitively connected to their rhythmic task. The RtD case also showed that the knowledge from one responsive level did not translate to the other.

As shown in the interviews, rhythm can generate strong emotions; from engaging social connectivity to the feeling of social exclusion. The same occurred during the RtD case; ignoring the particular breathing rhythm of the user caused serious negative emotions. The factors that influence emotion are complicated, designers need to keep the possibly strong effect in mind. It is unknown if a negative emotion results in poor performance.



KEEPING IT SIMPLE

In short, RE is different per case/person, can generate big emotions and aspect of the design interact with each other. This might sound as a daunting challenge, but not impossible for a designer. Design problems are often chaotic and interactive, therefore the process is approached in iterative steps.

Rhythmic Entrainment for design can benefit from the same approach; starting out by scoping the research (rhythmic task), researching possibilities (resources), setting a goal outcome (scenario), designing the product and through continuous testing, iterate on the previous cycle. The designer can add new aspects of the product each cycle, instead of trying to implement it all at the same time. This thesis helps the designer navigate the factors. Additionally, it simplifies some complex aspects of RE such as perception, time and context, to facilitate practical application.

Keeping it simple is also valuable for the user. The benchmark and RtD case showed that, when the rhythm changes too often, the person gets confused. This can generate negative emotions, keeping it simple and recognizable will benefit everyone.

CONCLUSION

This thesis aimed to *explore the potential of Rhythmic Entrainment in Product Design.* With the sub questions:

1. What is RE?
2. Which knowledge is needed to design with RE?
3. How to present and structure this knowledge?

Rhythmic Entrainment can create engaging and intuitive product interactions and thus be valuable for people and designers. However, designing with RE can be challenging because finding the right information about the topic is hard. This already starts at defining *what* it is. The definition of Rhythmic Entrainment can differ per research and comparable principles cause confusion. Even the definition of "rhythm" itself isn't straightforward. Adding to the complexity; design choices can influence multiple aspects of the interaction due to the relational nature of factors in RE. *The knowledge needed to design* with RE should be applied iteratively in the process, to simplify it while respecting the sensitivity of people to rhythm. The information gathered in this thesis is *presented and structured* in the RE4Design framework, developed for designers who want to learn more about RE.

This thesis showed there is potential in RE for designers; to create intuitive and engaging product experiences, but also to better understand temporality and vibration. Looking at strategic opportunities; the market is limited when compared to the widespread effect known in research. The RE4Design framework can be a starting point for informing designers about RE, helping them focus their research on the right information.

For researchers, RE as an affordance for movement can provide an approach to the concept of time. Merely the definition of rhythm as described in this thesis helps in understanding the way humans perceive their sonic context, by categorizing and predicting. Research in the neurology of listening to, playing or dancing to music underlines the possibilities (Krueger, 2011, 2014; Phillips-Silver & Trainor, 2005; Thaut et al., 2015; Windsor & De Bézenac, 2012)

Part 1 and 2 revealed which practical knowledge is still missing for understanding and designing with RE. Additionally, the RtD case resulted in a plethora of research directions relevant to the fields of RE, healthcare, data and tech development.

RECOMMENDATIONS

After writing each part of this thesis, questions about the topic remained. A few interesting research directions are discussed next.

For design engineering it is interesting to look into other industries that might benefit from RE; entertainment, sports, physical healthcare, embodied mental healthcare, social interactions, etc. A large diversity of ideas were theorized, but never explored due to time limitations. *A creative session with designers on the topic of RE* can reveal if valuable ideas emerge for different industries. This session can simultaneously test the RE4Design framework.

The effect of at least 2 humans entraining to the same rhythm has not been addressed enough when compared to its potential seen in the (real life) cases. These cases and the interviews show that shared RE can help people (re)connect in an astoundingly sensitive and intense manner. However, it is more complicated than any other type of RE, because other people are a resource as well. Therefore, further research into *social rhythmic entrainment* is needed[27].

The RtD case had 2 large limitations that reveal new research directions. In this case breath was perceived as rhythmic, participants showed a large variety of rhythms. However, research often only discusses breathing tempo (rate). The occurrence of different rhythms is unknown, likely due to the absence of effective measurement methods. *Gathering a variety of data sources about breathing rhythm* can be valuable in creating systems that can measure breathing rhythm as well.

Another limitation was the rhythm that was researched, breathing rhythm naturally causes more intense emotions than e.g. a tapping task. If the same *user test is done with any other human rhythm*, the results will likely be different. This can also indicate if the information about responsiveness (e.g. updating rate and character) can transfer across different rhythmic tasks or tempo ranges.

Finally, rhythm as affordance for movement has been argued and theorized, but not proven to exist. The research into it can illuminate how humans perceive time, as rhythm provides some time indication to which humans can respond.

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[27] *Master of Puppets – Metallica: Metalheads are a tight nit community of people connected through their music. What makes people connect over it?*

LIMITATIONS

The effectiveness of the RE4Design framework presented in this thesis unfortunately has not been tested with designers. However, the framework is based on structures commonly known by Industrial Design Engineers at the Delft University of Technology, increasing the likeliness of them understanding it.
Some factors that influence RE have not been included in this thesis due to their complexity.

1. The time until entrainment occurs has not been discussed in this thesis, the product interaction should be long enough.
2. Culture can have large influences on the perception of music[28] (Clayton et al., 2005), but in this thesis it is only briefly addressed.
3. Visual rhythms were not considered, but they are valuable.

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[28] *Vajra – Secret Chiefs 3: uses the Locrian note scale, which might be confusing for western listeners.*

MAKING THINGS COMPLICATED IS EASY,

MAKING THINGS EASY IS COMPLICATED

EPILOGUE

I often feel like a head on two sticks, merely existing for my brain. Sitting behind a computer all day has turned me into a "desk turtle". This disconnect between body and brain is a very relevant topic in our screen based society. I don't want to contribute to the creation of more products with screens, hence my interest in embodied interaction design.

Unintentionally, music has always been a way for me to get out of the weak, slow and disengaged mood of working behind a computer all day. So when I first heard about Rhythmic Entrainment I fully understood its value. A The way humans respond to rhythm in such an intuitive, uncontrollable (sometimes funny) and engaging way made me want to know more about the theory behind it.

When I started writing my thesis I had a few learning goals related to planning, mental health and personal development. I dived into the rabbit hole of research and thus struggled with the chaos of steering the information, causing some planning and communication issues.
However, the biggest learning came from an unexpected angle; I learned about what makes me happy. The conversations I had about my thesis showed I like being around people and that talking to experts from different perspectives stimulates my creativity.

I noticed the skills learned in my master (IPD) have been helpful, but I'm not sure if I will use them professionally any time soon. I like engaging experiences, music making and philosophy, I've missed this during my studies[29].
For now, I don't intend to pursue the topic of Rhythmic Entrainment any further in design or academics, I prefer exploring it in an embodied manner.
But first sleep[30].

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[29] Chaise Longue – Wet Leg: This will be my post thesis anthem.
[30] Vienna – Billy Joel: I'll be listening to Billy's advice.

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APPENDIX

A. RE CASES

Cases from research

Parkinsons

Parkinson patients improved their walking stability and pace while listening to a song with strong marching beats. (Haas et al., 1968)

Choir breath sync

Cardiac and respiratory efforts synchronize in choirs. (Cummins, 2009)

Breathing in sports

Breathing frequency adapts to the rhythm of the physical exercise (Kirschner and Tomasello, 2009)

Focus in the classroom

Background music helps students with learning disabilities to focus better. (Cripe,1986; HallamandPrice,1998; Savan,1999).

Improved labour

Evolutionary advantage of improved motor planning to rhythms while doing labour. (Müller and Lindenberger, 2011; Vickhoff et al., 2013)

Sync applauding

Automatic synchronization of hand clapping during applause. (Bechbache and Duffin, 1977; Paterson et al., 1986)

Music breathing

Musicians adapt their respiration rate more precisely to the tempo than non-musicians (Bernardi et al .,2006)

Trance drumming

Musical trance due to collective drumming or dancing (Szabo, 2006; Becker, 2010)

Rhythmic animals

Birds and sealions bobbing their heads to music and monkeys drumming to a rhythm (Wilson & Cook 2016)

Musical control

Non deliberate tapping along with feet or fingers to music (Iyer, 2002; janata et al. 2012)

Disrupted rhythms

Anger when your workout music stops all of the sudden (Lim et al. 2009)

Congenial amusia

People with congenial amusia are unable to hear rhythms. They can't dance to a beat either (Ayotte et al., 2002)

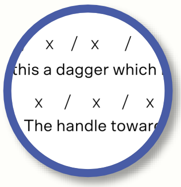
Social music

Music performance and listening strengthens social aspects between groups **(Fink et al., 2022; Krueger, 2011)**

Music genre dance rules

Try headbanging to a walz, it won't "feel" right (Windsor and de Bézenac, 2012; Leman, 2008; Burger et al., 2013).

Rhythm in speech



Much like the meter in poetry, in speech we put accent on certain words **(Cummins, 2009)**

Running on the beat

The time before a runner is exhausted was longer when a rhythm played in the same tempo as their cadence (Bood et al., 2013)

Social synchronized movement

Moving in synchrony with another person can create deep connections (Keller et al., 2014)

Emotion regulation of premature babies

The effects of playing soft rhythmic sounds have shown great advantages for calming down, socially connecting and regulating physiology of neonates (Krueger, 2011)

Cases from Rhythmic products

Somnox Sleep Robot

A pillow-shaped device that uses rhythmic breathing, calming sounds, and gentle movements to help individuals fall asleep faster and sleep better. Fisher price soothe 'n snuggle is similar, but for kids.

Apollo Neuro

A wrist wearable device that uses gentle vibrations to improve focus, relaxation, and sleep, and reduce stress and (social)anxiety. Hapbee smart wearable is similar but is worn on the head.

Weav run

A music app that uses rhythmic entrainment to create custom running playlists that sync with an individual's running pace or heartbeat. Rockmyrun run is similar.

Rocycle

Peleton bike classes based on the tempo of the music.

Endel

A sound app that uses artificial intelligence to generate personalized soundscapes that promote relaxation, focus, and sleep. Similar to Focus@will and brain.fm, but the latter two are not AI generated.

Satisfyer Pro

A sex toy that uses rhythmic pressure changes to stimulate orgasm.

Lovense

A sex toy that uses app-controlled vibrations that can be controlled by a partner or interact with the sextoy of the partner. The field of teledildonics has many versions of this product.

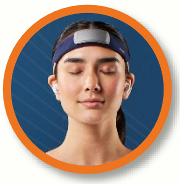
Hapbee sleep pad

a vibrating pad that can be put inside a pillowcase to help falling asleep. For babies the Lulla-vibe is put underneath the mattress.

Kasina Mind Media System

A meditation and relaxation device that uses light and sound to induce a meditative state and promote relaxation and focus. Similar to Braintap.

Muse Meditation



A headband that uses EEG technology to measure brain activity during meditation and provide real-time feedback to help individuals improve their meditation practice.

Moonbird

A handheld device that extends and shrinks to the rhythm of guided breathing exercises to promote relaxation and reduce stress and anxiety.

Sensate

uses a combination of gentle vibrations to the chest and soothing sounds to stimulate the vagus nerve, which is a key component of the body's parasympathetic nervous system, responsible for rest and relaxation.

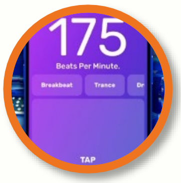
Glimp

supporting people in de-stressing through breathwork, using handheld vibration tools and audio.

Soundbrenner

A wearable metronome that uses haptic vibrations to help musicians keep a consistent tempo while playing music.

song BPM (beats per minute) calculator



A tool that helps individuals determine the tempo of a song by analyzing its rhythm and providing a numerical value that represents the number of beats per minute. This can be useful for musicians, DJs, or anyone who wants to synchronize their movements or actions with the rhythm of the music.

Bond touch

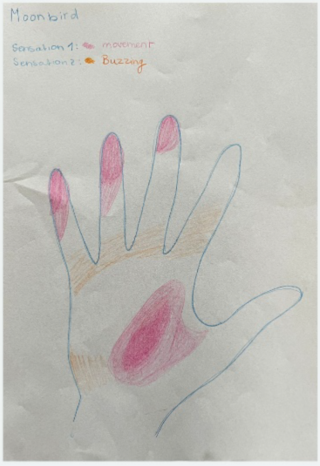
Heart math

B. Words for vibration

1. Buzzing
2. Pulsing
3. Tapping
4. Vibrating
5. Rumbling
6. Tickling
7. Nudging
8. Tingling
9. Shuddering
10. Trembling
11. Jolting
12. Oscillating
13. Throbbing
14. Shivering
15. Quivering
16. Fluttering
17. Humming
18. Whirring
19. Beating
20. Rolling
21. Swirling
22. Twisting
23. Bumping
24. Jumping
25. Jerking
26. Bouncing
27. Knocking
28. Hitting
29. Slapping
30. Punching
31. Flicking
32. Whipping
33. Swiping
34. Brushing
35. Stroking
36. Rubbing
37. Scratching
38. Tugging
39. Pulling
40. Stretching
41. Squeezing
42. Pinching
43. Crushing
44. Twanging
45. Plucking
46. Strumming
47. Picking
48. Snapping
49. Cracking
50. Clapping
51. Snapping
52. Sizzling
53. Crackling
54. Hissing
55. Popping
56. Clicking
57. Snicking
58. Whistling
59. Whooshing
60. Roaring
61. Rattling
62. Rustling
63. Crinkling
64. Flapping
65. Rustling
66. Scrunching
67. Creasing
68. Folding
69. Twisting
70. Rolling
71. Unrolling
72. Unfolding
73. Crumpling
74. Crushing
75. Smashing
76. Grinding
77. Friction
78. Gliding
79. Sliding
80. Skidding
81. Bouncing
82. Wobbling
83. Jiggling
84. Vibration
85. Resonance
86. Echo
87. Boom
88. Clang
89. Ringing
90. Tingling
91. Sparking
92. Zapping
93. Shocking
94. Taser-like
95. Stinging
96. Numbing
97. Hot
98. Cold
99. Pressure
100. Weighted

C. Benchmark Materials

Location on body



Vibration description (pick from list):

Nudging & whirring

Moonbird

Use context: handheld device, an app, used at home
Goal: Slow breathing, Stress reduction
Sense: Movement & vibration
Actuator: Brushless motor with moving mechanism

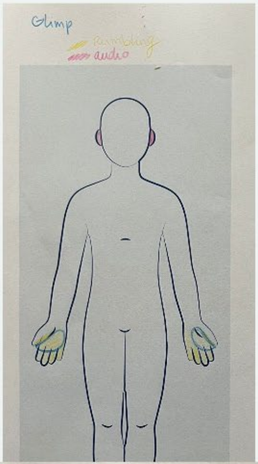
Rhythm

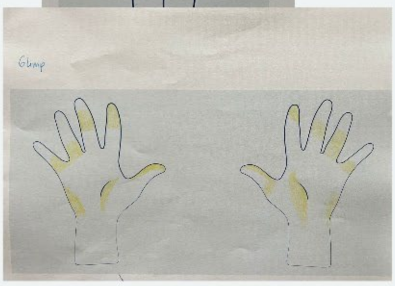
BPM: min. 2 sec, max. 20 sec in/out, exercises 4-4-4-4 box, 5-5, 3.5-4.5, 4-6
Type: Adjustable tempo & rhythm
Pitch/Amplitude: max amplitude is ~5mm
Character: Set/Responsive/Set adjustable to ...

Comments:

- Feels organic, like a breath, "breathing out" feels less natural than in due to the very constant tempo
- The buzz does make it feel a bit astmatic
- Gives off a buddy like character
- The sound is a little disturbing, likely due to the motor
- HRV showing in screen is horrible
- Is this actuator is quite limited, the fastest movement is 2s/5mm
- I like the "build it yourself" function, it allows people to experiment themselves

Location on body





Glimp

Use context: 2 handheld devices with an app, solo, mostly at home

Goal: Breathing exercises, reducing stress

Sense: Vibration & audio

Actuator: Lofelt

Rhythm

BPM: Changes per exercise, around 5-6 breaths

Type: Isochronous/Non-isochronous (depends on type)

Pitch (est.): 40Hz

Character: Set/Responsive/Set adjustable to intensity

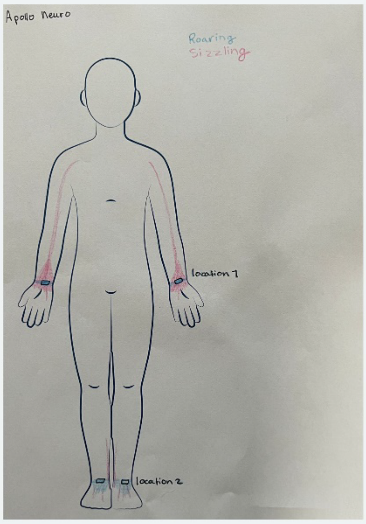
Comments:

- Vibration all over hand, hardest in top area and thumb
- Sensation changes a little when held differently and squeezed harder
- Vibration feels soothing, warm, inviting
- The audio does not add to the experience
- The wave shape & altering between the two hands can be a bit confusing

Vibration description (pick from list):

Rumbling

Location on body



Vibration description (pick from list):

Changes per type, constant sizzling in arteries. Changes per location& placement

Apollo Neuro

Use context: 2 wearables with an app, Anywhere (as a tool)

Goal: Energy, Social, Focus, Recover, Calm, Unwind, Fall asleep

Sense: Haptic vibration

Actuator: Lofelt*

Rhythm

BPM: Changes per type

Type: Altering isochronous rhythms

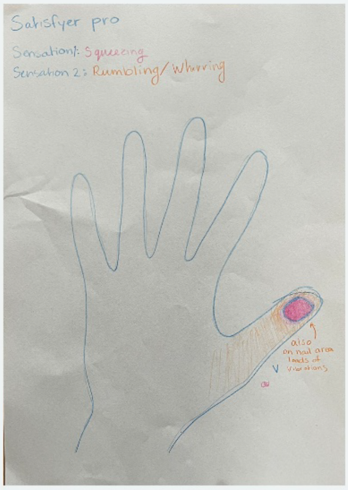
Pitch (est.): Changes per type

Character: Set/Responsive Set adjustable to intensity

Comments:

- Vibration moves further through body than just the application location
- Numbing can occur when exposed for too long
- Only noticeable effects when the vibration is VERY present
- Can cause overstimulation, disturbs mind patterns
- Doubtfull about the effects ("social" is BROAD)
- Vibration sensation changes when bodypart moves
- Apollo neuro toys with ANY variable a voicebox vibmotor can play with: Intensity, pitch, duration, waveform, rhythm
- Seems to be no rule of thumb here aside from "low energy" settings having lower pitches, intensity and tempo

Location on body



Sucking, rumbling, whirring

Satisfyer penguin

Use context: Handheld device, Solo at home

Goal: Orgasm

Sense: Movement & Vibration

Actuator: Brushless motor attached to suction cup

Rhythm

BPM: Changeable: 68BPM-~78Hz

Type: Isochronous

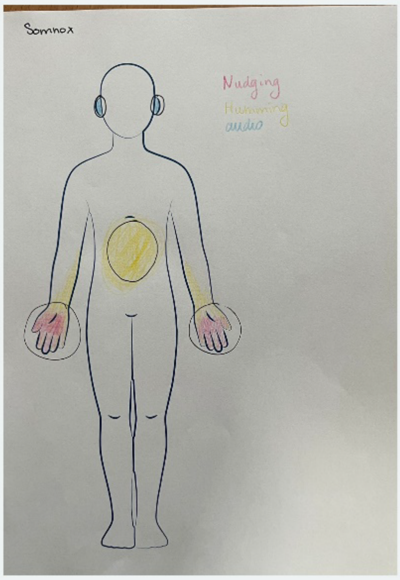
Pitch (est.): on highest: 78Hz

Character: Set/Responsive Set adjustable to tempo

Comments:

- Sensation changes a lot as the tempo changes: at a low tempo it feels like sucking, then it becomes a rumble and at the highest it becomes a whir
- The sucking feels superficial, the whirring will go throughout the entire bodypart
- Sensation changes when the product is placed against the skin differently
- Sucking is mostly noticeable in area inside the cup, more skin in is more effect
- Vibration numbing occurs eventually

Location on body



Vibration description (pick from list):

Nudging movement, humming

Somnox

Use context: Before falling asleep, in bedroom, alone

Goal: Slowing down breathing to induce sleep

Sense: Movement, Vibration & sound

Actuator: Airpump with little pillow

Rhythm

BPM: Depends on setting, around 5-6 breaths per minute

Type: Depends on type, isochronous/non-isochronous

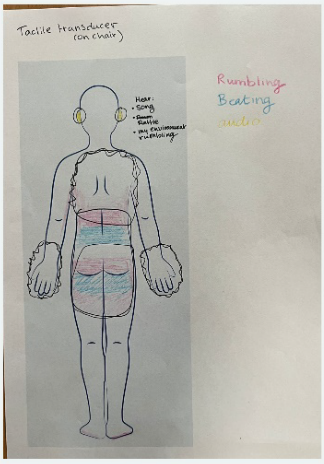
Pitch (est.): ?, approx 30mm deviation

Character: Set/Responsive /Set adjustable to frequency

Comments:

- Feels very natural, like a lung,
- but you do hear & feel the vibration & the solenoid click, which makes it less believable and it is a bit distracting
- I like the soft materials, it is pettable and friendly, but you do feel the sturdyness of the hard materials underneath, but that might make it "liveable"
- It is quite heavy, wouldnt want it laying on my arm
- The sensation changes when you change your body position in regards of the object
- The soundscapes do not add a lot to my opinion

Location on body



Rumbling, beating, weighted

Tactile transducer speaker

Use context: Mounted on large object (e.g. chair in theater)

Goal: Creating low Hz vibrations to improve user experience

Sense: Vibration

Actuator: Large solenoid vibration motor

Rhythm

BPM: Determined by song

Type: Random

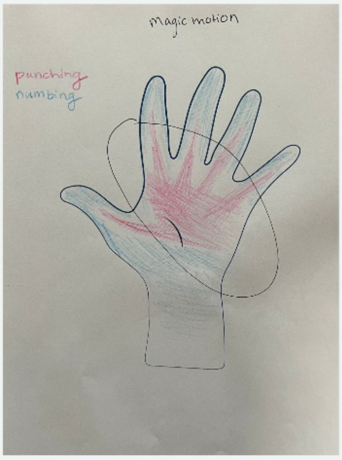
Pitch (est.): Range 20-80Hz

Character: Set/Responsive/Set adjustable to frequency &intensity

Comments:

- Bit scary, has a lot of force, is heavy, can shake a room and causes quick vibration fatigue
- If tuned to the right frequency and volume, the beat of the music is clearly represented in the vibrations
- With layered songs it is harder to distinct a rhythm in the vibration, it becomes one continuous rumble
- When the volume is too high, the speaker starts to shake the plastic of the housing, this unintentional shake sounds bad

Location on body



Vibration description (pick from list):

punching, numbing

Magic motion paint mode

Use context: Vibrating rod with app, in private with a partner (present or not)

Goal: Orgasm, Contact/Exploring with partner

Sense: Vibration & Visual

Actuator: Cheap vibration motor

Rhythm

BPM: (Live) altering

Type: Random

Pitch (est.): D#2 (78Hz)

Character: Set/Responsive (social)/Set adjustable to intensity

Comments:

- Very intense vibration, numbing occurs quickly, even at low intensity and slow tempos
- If the vibrator does not respond quick enough it is annoying
-

D. INTERVIEWS

For transcripts of the interviews, contact Frederike.

Interview questions:

1. What is your relation to the topic? (Job, expertise, etc.)
2. What is rhythm according to you?
3. Where do you experience rhythm? In your body?
4. What defines a nice rhythm? How do you feel when you're in rhythm? What is the character?
5. What defines a bad rhythm? What is the character?
6. Which elements from your surroundings can make or break the experience for you?

E: RTD ADDITIONAL RESEARCH

Rhythm in breath

Breathing might not appear as rhythmic as music, walking or tapping, as the movement is continuous and flowy. However, a breathing rhythm can consist of 4 distinguishable parts, as shown in fig. FIXME2. Often the breathing tempo is mistakenly called the breathing rhythm, but as said in section "Rhythm factors", these are not the same.

This error immediately reveals a problem for product design as (1) breathing exercises often alter the duration of each element to facilitate certain effects. E.g. breathing out longer than breathing in has been related to relaxation in the field of Soma breath. FIXME1 (2) When the product only measures the user tempo but presents the rhythm (breathe in.. breathe out..) some users with non-isochrone breathing patterns might be left out **(Wheatly, 2018)**.

In daily life, breathing is a physiological rhythm and it is directed by the autonomic nervous system. However, when a person takes active control over their breath, the somatic nervous system is used, meaning it becomes part of motor planning. Switching from the automatic to the somatic system requires some effort, as the person actively takes over control.

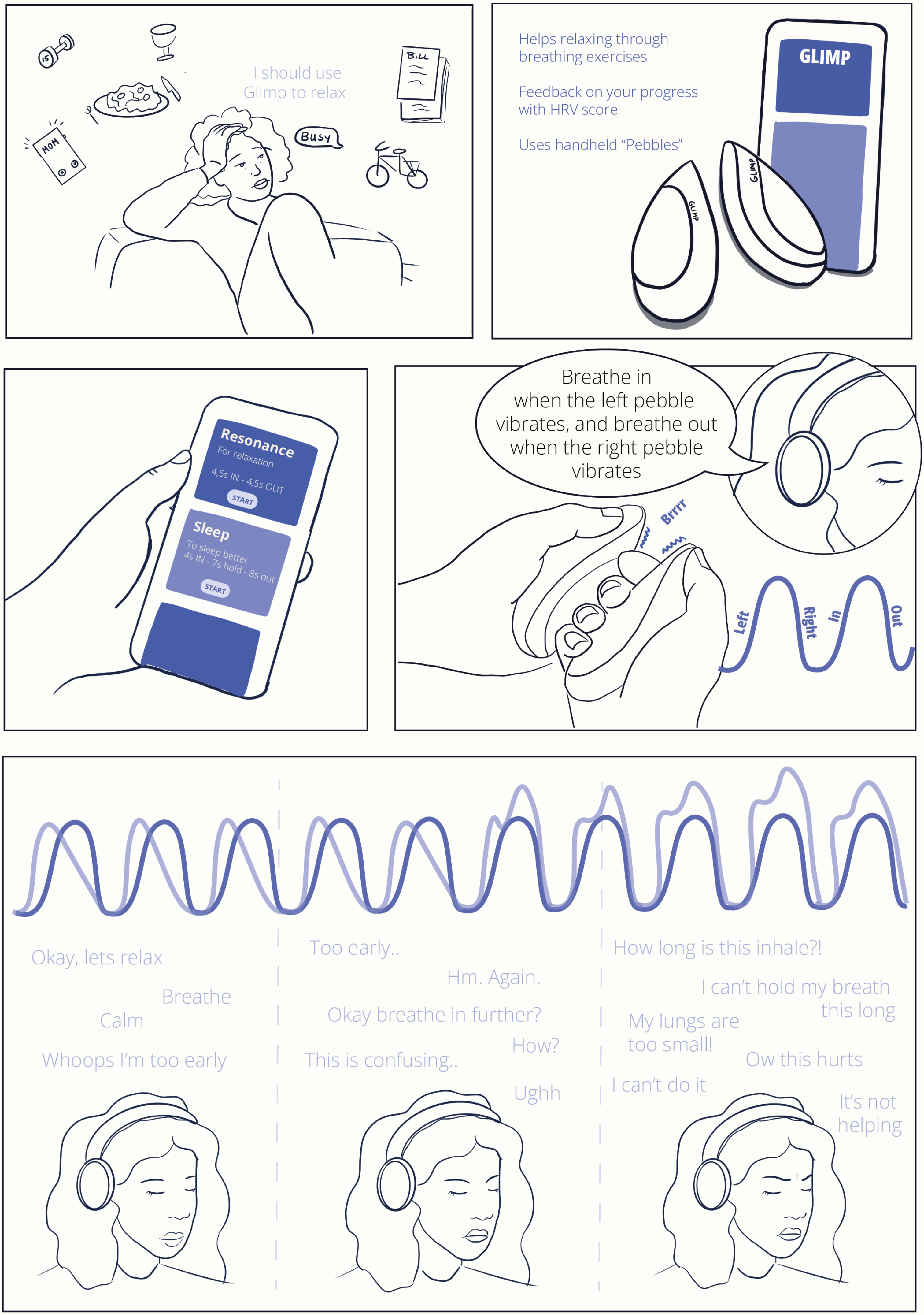
On average, the autonomic breathing tempo is between 12-18 breaths per minute (BrPM), in heavy exercises it can go up towards 36 BrPM (Blackie et al., 1991). In controlled (not autonomic but somatic) breathing exercises, this rate can go down towards 4-6 breaths per minute. Heartrate differs as well.

Sensors for breath

In order for Glimp to be responsive to breath, it needs to be able to measure the breathing rhythm and/or tempo of the user. For this case the ability to measure is important; can it measure the values accurately and fast enough? What does it measure, tempo or rhythm? The context is important as well; where will the measurement take place on/around the body?

Name	Measures	Location	Accuracy	Timing	Type	Notes	Source
PPG	Oxygen levels in the blood	Preferably on "thin" skin	Medium (2 bpm error)	Medium/slow	Tempo	The sensor needs to be placed against the skin tightly	(Iqbal et al., 2022)
Gyroscope/ Accelerometer	Chest movement	Strap around chest	High in lab setting, medium in products	Fast	Rhythm & Tempo	Requires filtering out any other additional movements	
Flex sensor	Chest expansion	Strap around chest	High in lab setting	Fast	Rhythm & Tempo	Only available in lab setting	
Microphone	Airflow	Next to mouth/nose	Medium in lab setting otherwise low	Fast	Rhythm & Tempo	If the airflow speed of the person is low, the breath will not show up	
Visual analysis	Chest, shoulder, throat movement, face coloration	Camera placed in front of the person	High	Fast	Rhythm & Tempo	Requires person to sit still in front of camera	(Deo Mehta & Sharma, 2023)

Table FIXME2 shows the sensors currently available on the market.



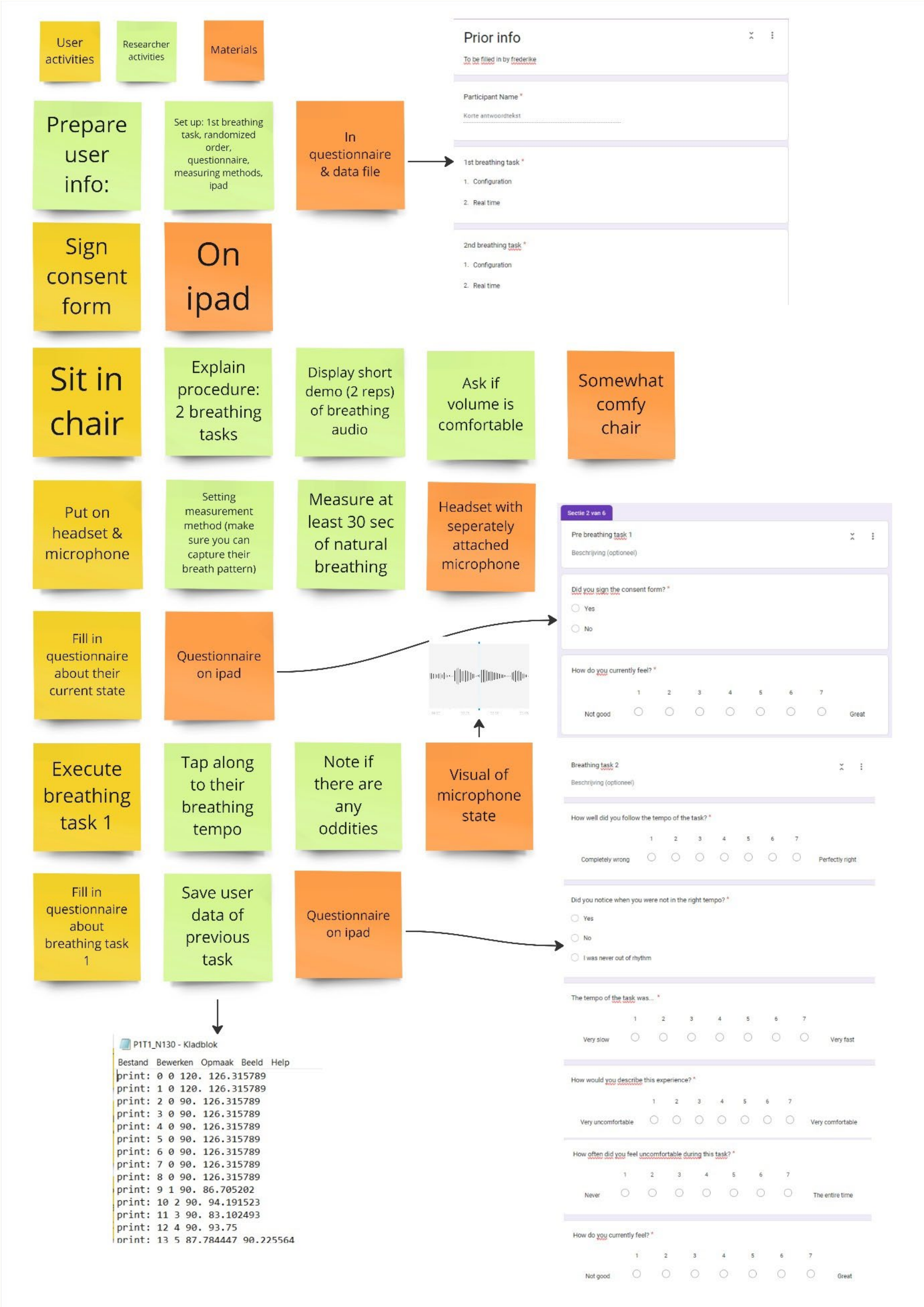
15
MOM
Bill
Busy
I should use
Glimp to relax
Helps relaxing through
breathing exercises
Feedback on your progress
with HRV score
Uses handheld “Pebbles”
GLIMP
GLIMP
GLIMP
Resonance
For relaxation
4,5s IN - 4,5s OUT
START
Sleep
To sleep better
4s IN - 7s hold - 8s out
START
Breathe in
when the left pebble
vibrates, and breathe out
when the right pebble
vibrates
Brrrr
Left
Right
In
Out
Okay, lets relax
Breathe
Calm
Whoops I'm too early
Too early..
Hm. Again.
Okay breathe in further?
How?
This is confusing..
Ughh
How long is this inhale?!
I can't hold my breath
this long
My lungs are
too small!
Ow this hurts
I can't do it
It's not
helping

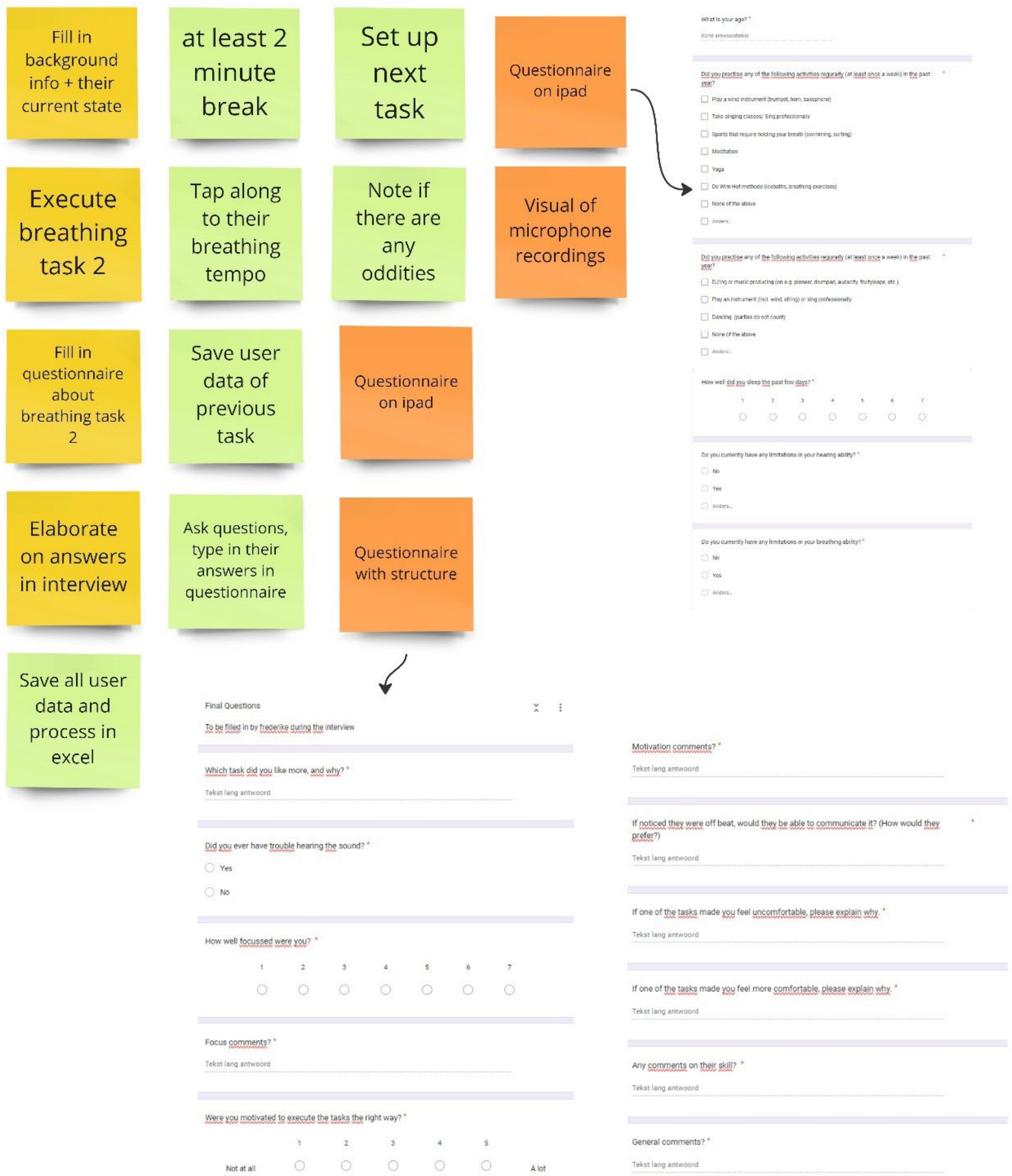
F: RESEARCH THROUGH DESIGN DIARY

Research setup

Factors

Alternating factors: responsivenesslevel	
Configuration	Real time
Stable factors	
Goal tempo (breath per minute)	7,5
Goal Rhythmic ratio	0,8:0,2:0,8:0,2
Duration each section (ms)	3200:800:3200:800
Entraining to	Tempo
User data input	Breathing tempo (manually)
Application method	Audio (headset)
Pitch	40Hz IN 80Hz out
Repetitions	37
Duration of entire task	~5 min
Acceptable error range	Too fast: 3000 Too slow: 1000


User activities
Researcher activities
Materials
Prior info
To be filled in by frederike
Participant Name *
Korte antwoordtekst
1st breathing task *
1. Configuration
2. Real time
2nd breathing task *
1. Configuration
2. Real time
Prepare user info:
Set up: 1st breathing task, randomized order, questionnaire, measuring methods, ipad
In questionnaire & data file
Sign consent form
On ipad
Sit in chair
Explain procedure: 2 breathing tasks
Display short demo (2 reps) of breathing audio
Ask if volume is comfortable
Somewhat comfy chair
Put on headset & microphone
Setting measurement method (make sure you can capture their breath pattern)
Measure at least 30 sec of natural breathing
Headset with seperately attached microphone
Sectie 2 van 6
Pre breathing task 1
Beschrijving (optioneel)
Did you sign the consent form? *
Yes
No
How do you currently feel? *
Not good
Great
Fill in questionnaire about their current state
Questionnaire on ipad
Execute breathing task 1
Tap along to their breathing tempo
Note if there are any oddities
Visual of microphone state
Breathing task 2
Beschrijving (optioneel)
How well did you follow the tempo of the task? *
Completely wrong
Perfectly right
Did you notice when you were not in the right tempo? *
Yes
No
I was never out of rhythm
Fill in questionnaire about breathing task 1
Save user data of previous task
Questionnaire on ipad
The tempo of the task was... *
Very slow
Very fast
How would you describe this experience? *
Very uncomfortable
Very comfortable
How often did you feel uncomfortable during this task? *
Never
The entire time
How do you currently feel? *
Not good
Great
P1T1_N130 - Kladblok
Bestand Bewerken Opmaak Beeld Help
print: 0 0 120. 126.315789
print: 1 0 120. 126.315789
print: 2 0 90. 126.315789
print: 3 0 90. 126.315789
print: 4 0 90. 126.315789
print: 5 0 90. 126.315789
print: 6 0 90. 126.315789
print: 7 0 90. 126.315789
print: 8 0 90. 126.315789
print: 9 1 90. 86.705202
print: 10 2 90. 94.191523
print: 11 3 90. 83.102493
print: 12 4 90. 93.75
print: 13 5 87.784447 90.225564

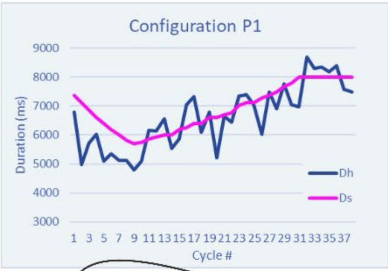


Fill in background info + their current state
at least 2 minute break
Set up next task
Questionnaire on ipad
Execute breathing task 2
Tap along to their breathing tempo
Note if there are any oddities
Visual of microphone recordings
Fill in questionnaire about breathing task 2
Save user data of previous task
Questionnaire on ipad
Elaborate on answers in interview
Ask questions, type in their answers in questionnaire
Questionnaire with structure
Save all user data and process in excel
What is your age? *
Korte antwoordtekst
Did you practise any of the following activities regurarly (at least once a week) in the past year? *
Play a wind instrument (trumpet, horn, saxophone)
Take singing classes/ Sing professionally
Sports that require holding your breath (swimming, surfing)
Meditation
Yoga
Do Wim Hof methode (icebaths, breathing exercises)
None of the above
Anders...
Did you practise any of the following activities regurarly (at least once a week) in the past year? *
DJ'ing or music producing (on e.g. pioneer, drumpad, audacity, fruityloops, etc.)
Play an instrument (incl. wind, string) or sing professionally
Dancing (parties do not count)
None of the above
Anders...
How well did you sleep the past few days? *
1 2 3 4 5 6 7
Do you currently have any limitations in your hearing ability? *
No
Yes
Anders...
Do you currently have any limitations in your breathing ability? *
No
Yes
Anders...
Final Questions
To be filled in by frederike during the interview
Which task did you like more, and why? *
Tekst lang antwoord
Did you ever have trouble hearing the sound? *
Yes
No
How well focussed were you? *
1 2 3 4 5 6 7
Focus comments? *
Tekst lang antwoord
Were you motivated to execute the tasks the right way? *
1 2 3 4 5
Not at all
A lot
Motivation comments? *
Tekst lang antwoord
If noticed they were off beat, would they be able to communicate it? (How would they prefer?) *
Tekst lang antwoord
If one of the tasks made you feel uncomfortable, please explain why. *
Tekst lang antwoord
If one of the tasks made you feel more comfortable, please explain why. *
Tekst lang antwoord
Any comments on their skill? *
Tekst lang antwoord
General comments? *
Tekst lang antwoord

Data analysis

Data available

The duration of their breath prior to and during the task



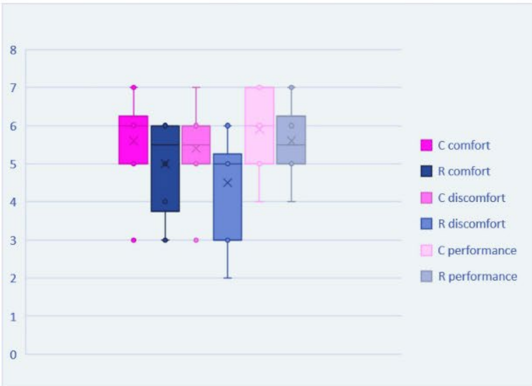
Performance score for each participant:

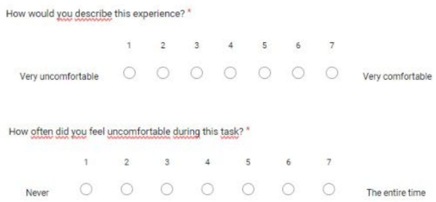
$$P = (Ds,goal - Dh,end) * \frac{(Dh,end - Dh,start)}{(Dh,goal - Dh,start)}$$

Ds,goal= goal duration of the sound at the end of the task
Dh, end = average duration of 5 breaths of the human at the end of the task
Dh,start= duration of human breath at the baseline measurement

New table

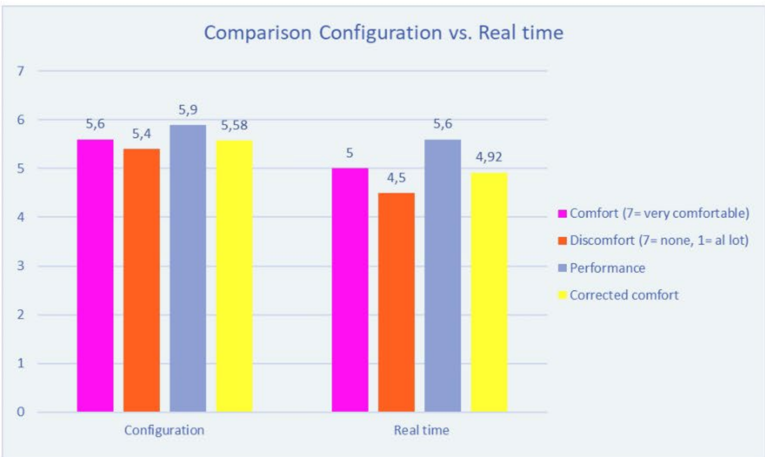
Rank	Plow	Phigh
1	2500	8000
2	2000	2500
3	1500	2000
4	1000	1500
5	500	1000
6	250	500
7	0	250





Corrected comfort: The comfort score (comfort & discomfort) corrected with a factor of their performance

Cc= Comfort*0,4+Discomfort*0,4+Performance score*0,2



Is the current method of calculating performance and corrected comfort correct?

Should it include more factors?

e.g. how did they experience the tempo of the task (too fast, too slow)

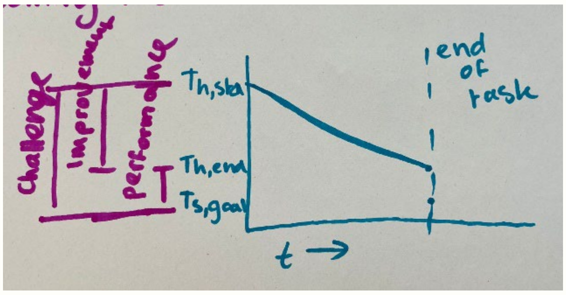
e.g. improvement of mental state (how do you feel? Pre and post task)

e.g. prior skill (noticed the trained people were quite a lot better)

Do i need to do a statistical analysis?

Small n, quite specific situation

Calculations



- Can’t just take the difference between the end tempo of the human and the goal tempo, not fair to people who started with a way higher tempo
- Weighted performance is the performance * a factor indicating the difficulty of their task (based on the challenge and their improvement)
- A lower weighted performance means the person did good (for their level)
- Weighted performance, how far away from the goal the participant is, weighted by how well they changed compared to the challenge they faced:
  $P = (Ds, goal - Dh, end) * \frac{(Dh,end - Dh,start)}{(Dh,goal - Dh,start)}$

Diary

23-6

Activities:

- Determine "start scenario" & Desired outcome scenario
  - This case is quite confined already, how representative is it for other RE4D cases?,
  - Written down in Miro per section written down in schematic, but added a scenario story
- Choose RE task for 1st iteration
  - Needed some prior research into the topic
  - Chose "Motor planning"
- Ideate
  - Realized i wont be able to do ideation rightaway bc i first need figure out the already existent resources

Learned:

- Design problem comes after defining the desired outcome scenario

26-6

Activities:

- Determine available resources
    - Made quick scenario and colored the physical resources available to the user, eventually argued the relational resources, listed them
    - Sorted them into human-artefact-environment (or anything in between)
- Ideate
    - Got stuck again bc I need to define "responsiveness"

27-6

Activities:

- Collect information
    - Further elaborated categories of responsiveness (information collection)

28-6

Activities:

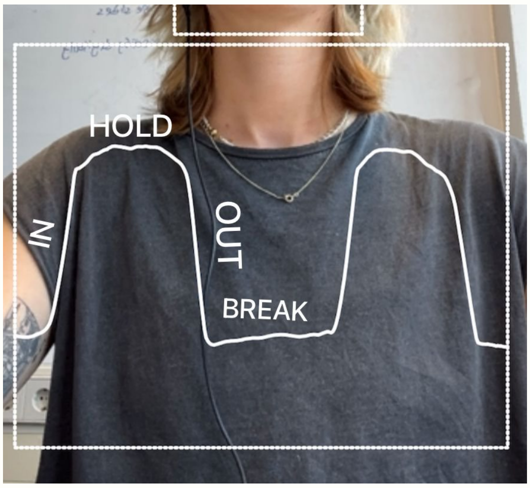
- Collect information
    - Asked Robin about the limitations of the current system (sensor, software and data wise) and future expectations
- Ideate
    - I didnt really use the resources as much anymore to create any new ideas
    - Decided that the focus should lie on creating a prototype that can be adjusted to function for multiple tests
- Problem definition
    - Read through existing papers that did similar things, looked at how they did it

30-6

Activities:

- Building proto
    - Started with trying to use the GEM repository, but assessed that their setup is not suiting for my goals

- Tried building it myself on a seeeduino but figured out a single arduino can't run multiple tasks
    - Tried working with a timing library to still use one computer, but that didnt work either
- Research
    - Breath feels continuous but due to the different phases of the breath it is binary.



3-7

Activities:

- Building proto
    - Considered other programs, there are apps that can also match a tapping beat?
- Prototyping
    - Talked to Aadjan van der Helm (Tu delft), he advised me to use MAX/Msp for my proto as it is audio driven software and it can be adjusted to other prototypes
    - Tried finding an algorithm to represent configuration
    - Chose which actuator to use for the rhytm: lofelts w/ aux plug
- Setting up requirements for system
    - Decided 1 system should be able to handle different forms of responsiveness
    - Found some variables that are important to input, but also to retrieve
    - Start easy: slow tapping tasks, work up to breathing
- Research
    - Sensors for breathrate, google, talk with robin, ask around (arjen)

4-7

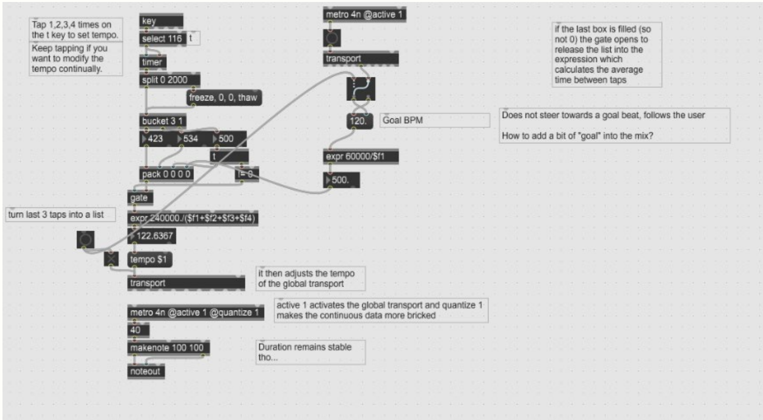
Activities:

- Building proto
    - Debunked the GEM paper about the topic; cant use their algorithm ☹
    - I now understand the importance of understanding rhythm properly before designing with it
    - Tried pulling the repository from GEM, no succes, too much effort

    - Made an excel file that can do "configuration" using BPMstart, BPMgoal and outputting tin, Din, tout, Dout
- Setting up requirements for system
    - Found a way to (using variables) change the type of responsiveness of the system
    - With the "strictness rate", alpha, however you'd like to call it
    - For breath, can also do a wizard of oz (tapping along to the breath of the user)

17-8

Activities:

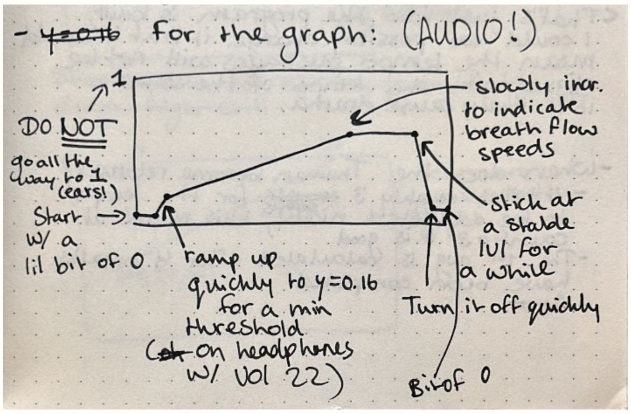


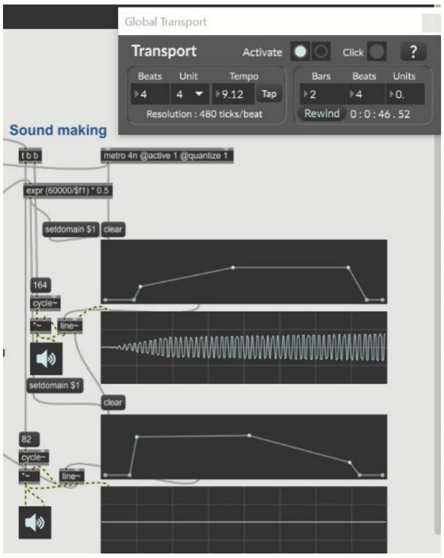
- Building proto
    - Found an online patcher that works really nicely, https://cycling74.com/forums/how-to-create-a-tap-tempo-in-max had to figure out how it works first
    - Adjusted it to take the goal rhythm into account a bit more
    - When is the tap correct? Too early? Or too late? How to judge the quality of the entrainment?
    - Continuous changing of rhythm can be quite uncomfortable, the tone glitches, super confusing

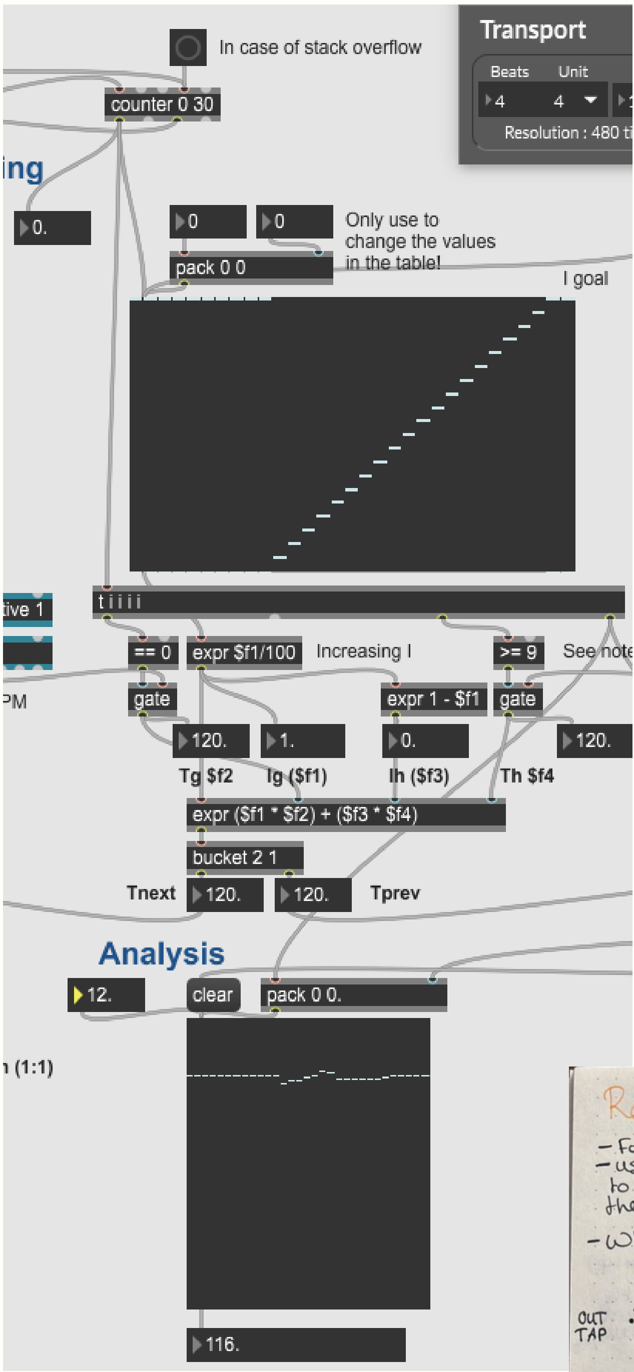
18-8

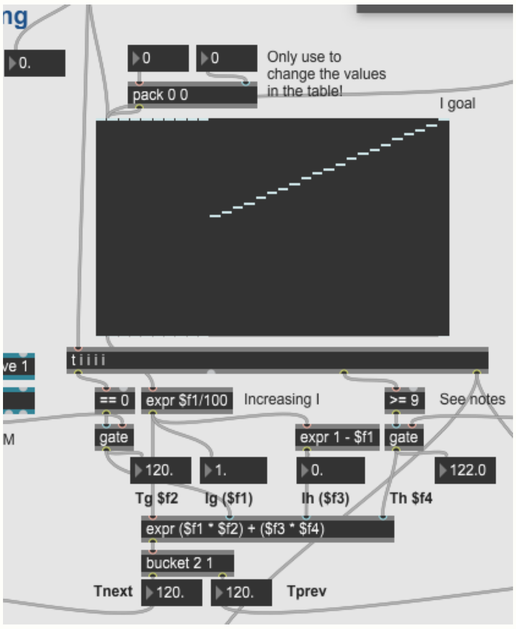
Activities:

- Made the note duration adjustable based on the tempo
- Ratio of rhythm is now 1:1!
- Found a method to export the max console to excel so I can analyze the quality of the tapping task
- Still have to figure out which parameters indicate a successful tapping task



- 

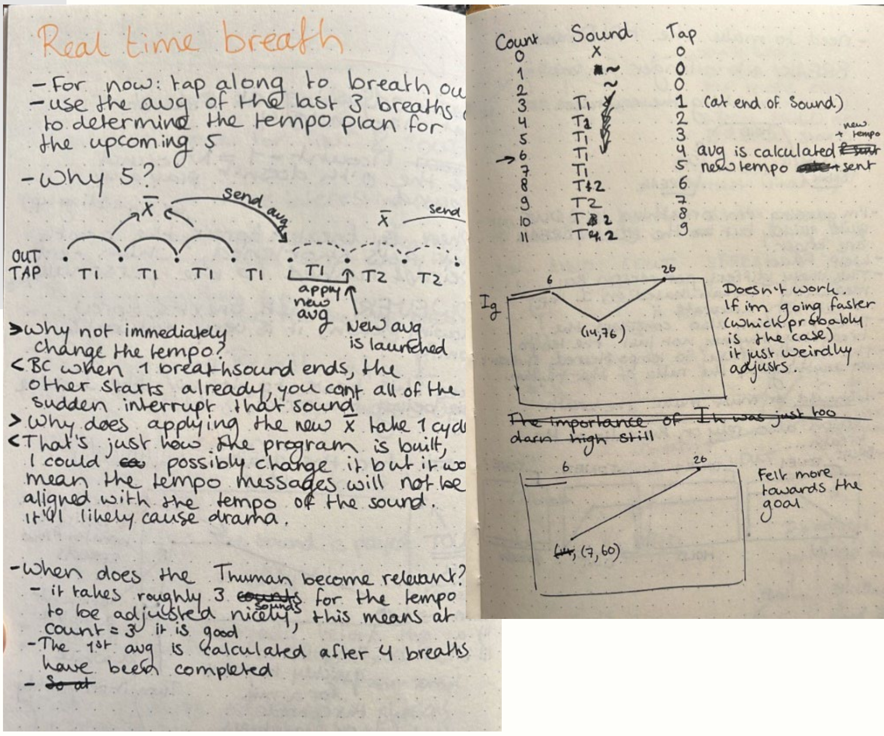




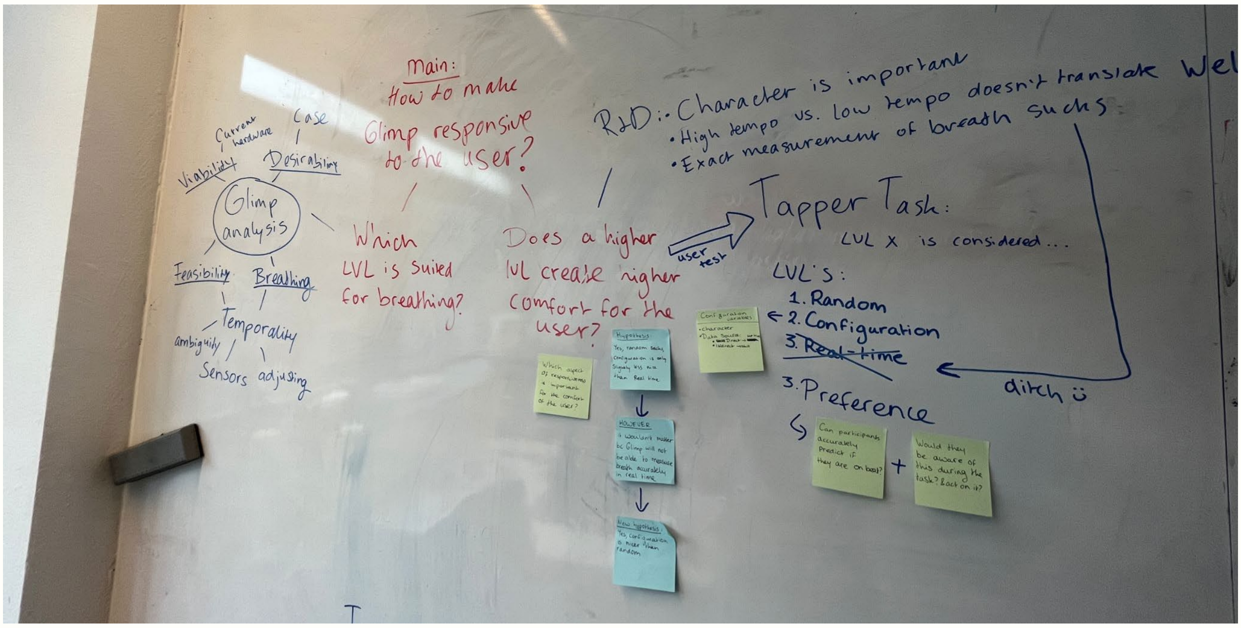
It appears real time can benefit from being a bit stricter

The previous graph paid too much attention to the user rhythm at the start.

The 2nd graph has an importance of at least 0,5.



01-09



- Went back to the original goal of this section and realized that the earlier research had already resulted in some valuable conclusions which change the breathing task test (as seen in the research Q whiteboard scribbles, next to “RTD:”)

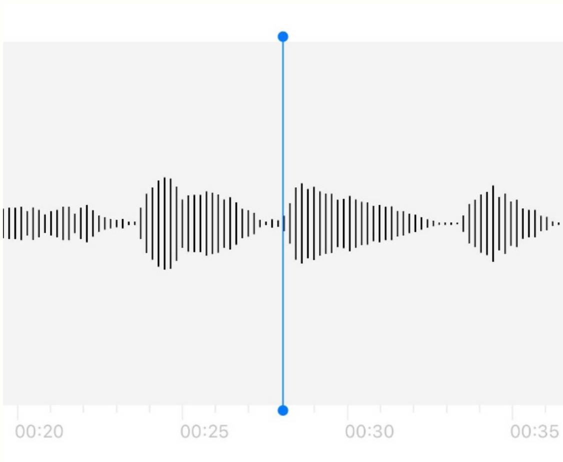
5-9

- Discussed with Jefta and Gijs what to do with the breathing task research
- Real time does not appear realistic due to sensor and data limitations, combined with feasibility & viability for Glimp.
- How to create value for Glimp, Research and my thesis regardless of wether real time will work anytime soon?
- Changed research question based on the Desirability, Viability and Feasibility assessment of Glimp.

6-9

- Drama. The patcher I took from the forum is not correct.It calculates the time between the taps, which means it only measures the tempo & you can easily go out of phase entirely.
- The measurement should be between the occurrence of the sound and the tap, so the program adjusts for the error.
- Have to completely figure out how to built a timer that can calculate wether the person was too quick or too slow, calculate the error and the duration of the user

11- 09



- Testrun went okay, but noticed that the rhythm on the pebbles did not work for me because I have to tap along to the breathing of the user, but I hear the pebbles as well. Thus, output will be audio only
- Will attempt to do something with the microphone:
- Google fit+ struggles with POC's

12-09

- Microphone setup does not work bc people do not breathe as loudly as I do (asthmatic girlies <3)
- Program shows some errors here and there, does print data when the breath is tapped but sometimes it delays and then the other data has already shifted

13-09

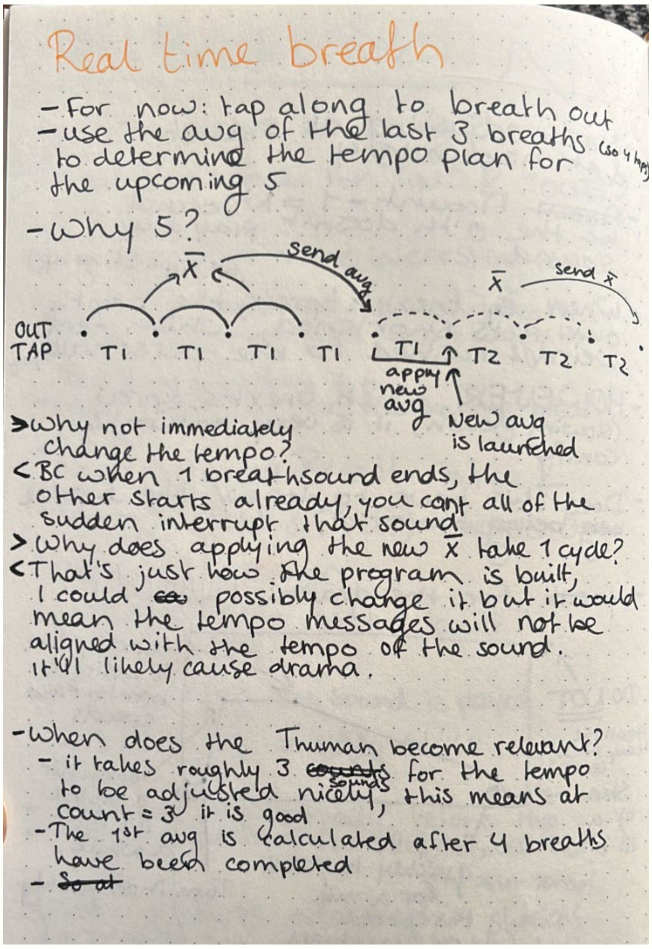
- Practised tapping along to breath with Jasmijn (Physiotherapist roommate)
- Tapping along to a breathing pattern is hard:
  - Breathing consists of timing of each of the elements (IN, HOLD, OUT, BREAK)
  - Sometimes people puff out quite loudly, but then decrease their speed at the end
  - Where the person breathes (belly, chest, throat) makes a huge difference
  - Shallow breathers exist, they are hard to read
  - It feels a bit awkward to stare at someones chest for 5 minutes straight
- Some difference in skill shows up in the results of the users.
- How often should "real time" update? An update every breath makes it very arhythmic, which makes it harder to follow
- It requires accurate measurements.
- Funny: when asking if they'd like a button to slow down or increase the volume, many of them suggest that the device should do that automatically

14-09

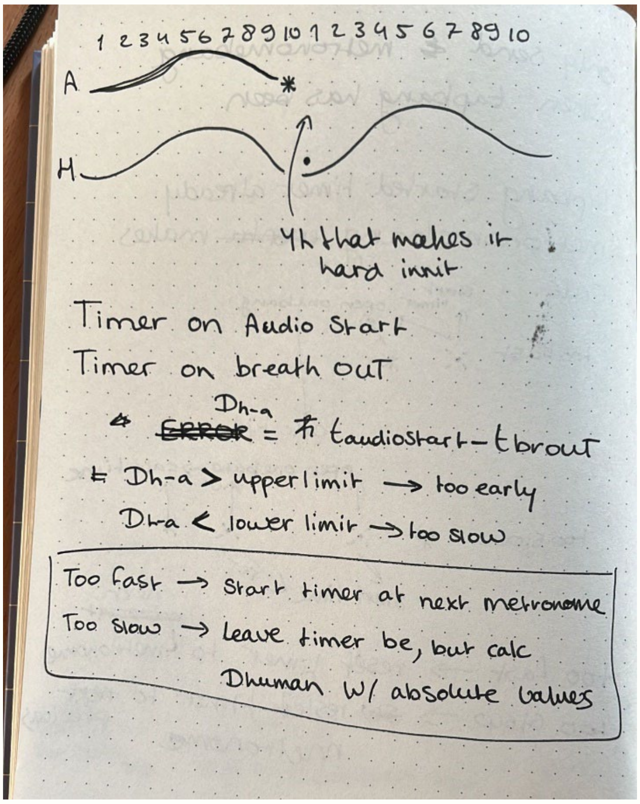
- Determine ambiguity of sound based on their skill?
- There is a big difference between natural breathing and steered breathing
- People have certain expectations for breathing exercises, they should be quite slow from the start, not start exactly at their natural breathing pattern

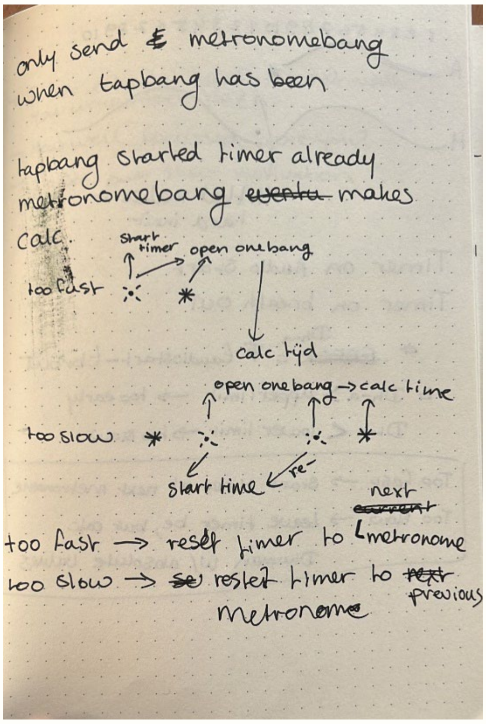
15-09

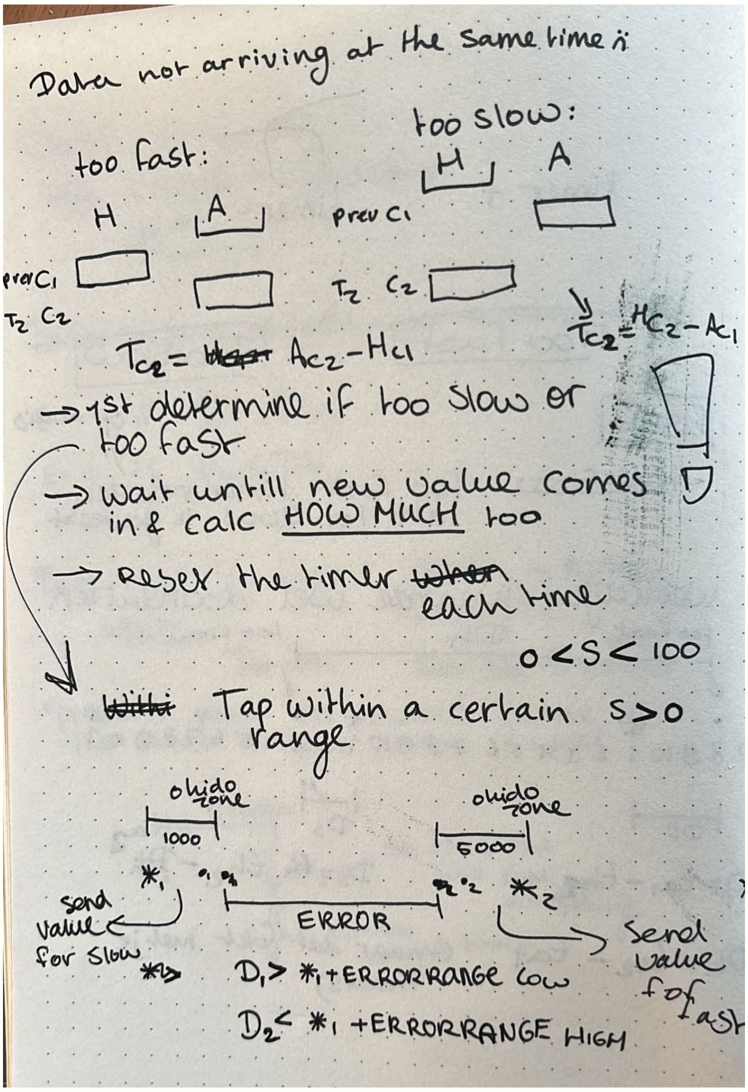
- Export the absolute time of the events, not interval time
- Data might arrive at different times, make sure they align

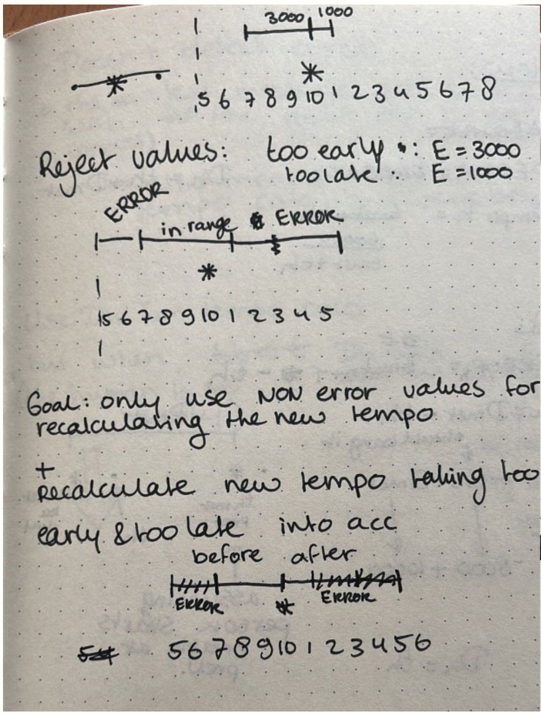


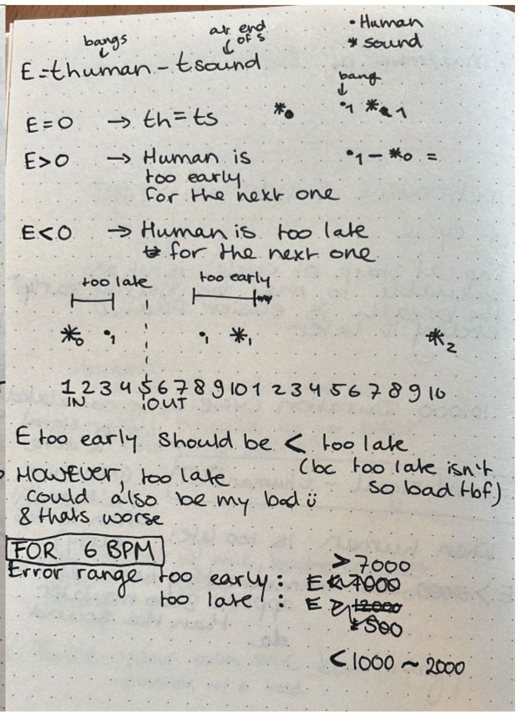
From notebook:

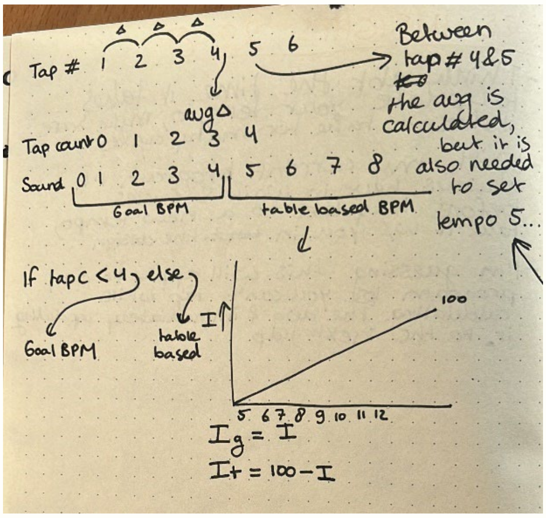


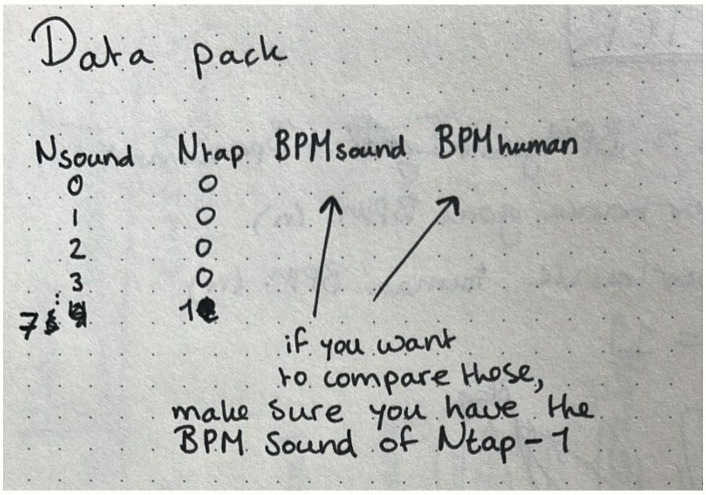





3000
1000
5 6 7 8 9 10 1 2 3 4 5 6 7 8
Reject values: too early : E = 3000
too late : E = 1000
ERROR
in range
ERROR
5 6 7 8 9 10 1 2 3 4 5
Goal: only use NON error values for recalculating the new tempo
+
Recalculate new tempo taking too early & too late into acc
before
after
ERROR
ERROR
5 6 7 8 9 10 1 2 3 4 5 6


bangs
at end of s
• Human
* sound
E = thuman − tsound
bang
E = 0 → th = ts
E > 0 → Human is too early for the next one
E < 0 → Human is too late for the next one
too late
too early
1 2 3 4 5 6 7 8 9 10 1 2 3 4 5 6 7 8 9 10
IN
OUT
E too early should be < too late
HOWEVER, too late could also be my bad
& thats worse
(bc too late isn't so bad tbf)
FOR 6 BPM
Error range too early : E > 7000
too late : E > 500
< 1000 ~ 2000


Tap # 1 2 3 4 5 6
Between tap # 4 & 5 the avg is calculated, but it is also needed to set tempo 5...
avg Δ
Tap count 0 1 2 3 4
Sound 0 1 2 3 4 5 6 7 8
Goal BPM
table based BPM
If tapC < 4, else
Goal BPM
table based
I
100
5 6 7 8 9 10 11 12
Ig = I
It = 100 − I


Data pack
Nsound Ntap BPMsound BPMhuman
0 0
1 0
2 0
3 0
7 8 1
if you want to compare those, make sure you have the BPM Sound of Ntap − 1

G. Additional information for RE 4 Design

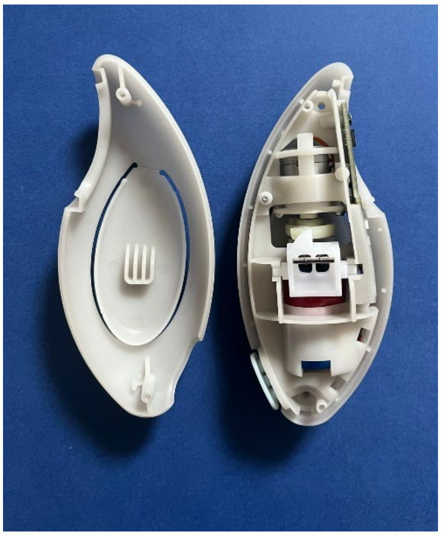
Eccentric rotating mass (ERM) are the cheapest and can be as small as a shirt button. Simply put, it is a motor with some mass attached on only one side of the axis. Therefor it shakes the encasing, creating a vibration. ERM's can differ a lot in their force and frequency, depending on the size of the mass. More force means a lower maximum frequency, but it also increases the size of the ERM and their response time. The motor needs to accelerate before any vibration can be sensed.

A linear resonant actuator (LRA) or voice-coil haptic motors are a lot like a speaker. They produce vibration through the use of a spring-mass system. When an electrical current is passed through the coil surrounding the magnet, it creates a magnetic field that attracts and repels the mass, causing it to vibrate back and forth. The spring helps to control the frequency and amplitude of the vibration. It has low power consumption, high precision vibration control and they are reliable. However, they may be more expensive than other vibration motors, have limited vibration strength, and can be sensitive to temperature changes.

A solenoid vibration actuator is a type of linear motor that produces vibration through a reciprocating motion. It consists of a solenoid coil that generates a magnetic field when an electrical current is passed through it. This magnetic field interacts with a plunger or armature, causing it to move back and forth rapidly, thereby creating vibration. They are simple to use, low cost, very reliable and efficient in creating strong vibrations. However, they have a limited frequency range and vibration amplitude control.

Another method of applying the rhythm is by using common electronic motors (brushless, DC, AC, etc.) in combination with a translating mechanism. Moonbird uses a electromotor in combination with a mechanism that translates the rotary movement to a linear movement of the "wings" moving out and in. The product communicates the rhythm through pressure on the hands from the movement of the wings. The opportunities for creating new interactions are endless; there are many types of motors, and mechanisms can be designed specifically for each product. This means designers are able to easily tweak the sensation. It allowed Moonbird to imitate natural movement such as a breath moving the chest up or down. However, this method can limit the ways the product can be used, as the mechanism cannot be changed during usage. Moonbird cannot facilitate a large variety of breathing patterns when compared to its vibration motor based competitors, as shown the benchmark results in appendix C.

For product design there are many ways to make audio, there is a speaker for every range, size and price. A designer can determine their product needs and choose an actuator accordingly.



APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair ______ date 07 - 03 - 2023 signature ______

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 32 EC

Of which, taking the conditional requirements into account, can be part of the exam programme 30 EC

List of electives obtained before the third semester without approval of the BoE

X YES all 1st year master courses passed

NO missing 1st year master courses are:

name Robin den Braber date 15 - 03 - 2023 signature RdB

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **. Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: V APPROVED NOT APPROVED

Procedure: V APPROVED NOT APPROVED

comments

name Monique von Morgen date - KE 21/3/2023 signature MvM

Rhythmic entrainment for design

project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 20 - 02 - 2023 02 - 10 - 2023 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

Rhythmic entrainment is the principle of 2 oscillating/vibrating objects that over time end up having the same rhythm, humans can also "entrain" themselves to a rhythm. E.g. marching is easier when music is playing. (Trost & Vuilleumier, 2015, Stephan et al., 2000)
The research into this form of Rhythmic entrainment has been approached from many angles (history, biology, music, sociology, etc.) , but has limited product applications even though rhythms are present everywhere in daily life: daylight, seasons, music and biological processes.

Designers are always looking new product interactions, but applying previously unused theories can be risky. Applications of rhythms in products are found in the wellness/health sector, especially meditation tools are gaining popularity. Glimp helps reduce stress by providing meditation audio, coaching and handheld vibrating meditation tools that respond to the user intuitively. In the future, they aim to make the background audio suit the vibration of the handheld tools to help users better "tune in" into their body.

Embodied experience theory states we can perceive without the need for mental representation, we perceive our world through our bodies. (Wilson, 2002) E.g. a doorhandle can fit a hand, thus it stimulates the behavior of putting your hand on the doorhandle. Affordances are opportunities for action, in this case the shape of the doorhandle poses the opportunity use the hands. (Chemero, 2009)

The temporal effect of rhythms are a form of affordances. If a sound repeats itself within the same duration (a rhythm) (London, 2004), then we can predict when the next similar sound will arrive. Perceiving (or predicting) the rhythm happens with our body (Krueger, 2014, Cummins, 2009). Moving a bodypart to the expected occurance of the next "dominant" sound (London, 2004 & Kotz, Ravignani & Fitch, 2018), a.k.a. dancing on beat, gives us dopamine. It helps in emotional regulation and motor planning but in the context of parties it can create deep social connections as well (Trost, Labbé & Grandjean, 2017). The music/entertainment industry is aware of the positive effects, but does not apply the theory as much. Image 2 provides a visual explanation.

During this product design thesis, the resources (monetary, time, knowledge) will not suffice to dive into the internal processes of rhythmic entrainment (neurology). For better integration into product design, the affordances within rhythms and its' positive effects are more relevant.
There are many factors that influence whether a theory is used in products or not. The aim should not be to provide a full application of the theory in product design in general. The desirability for users is key, but viability and feasibility should not be ignored.

space available for images / figures on next page

introduction (continued): space for images

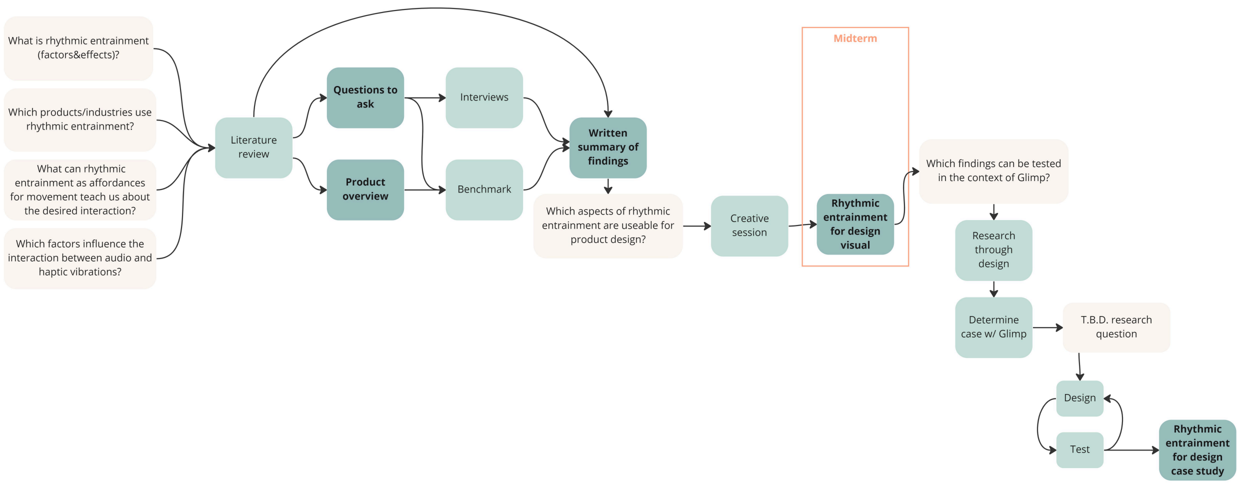


image / figure 1: Visual explanation organisation of thesis

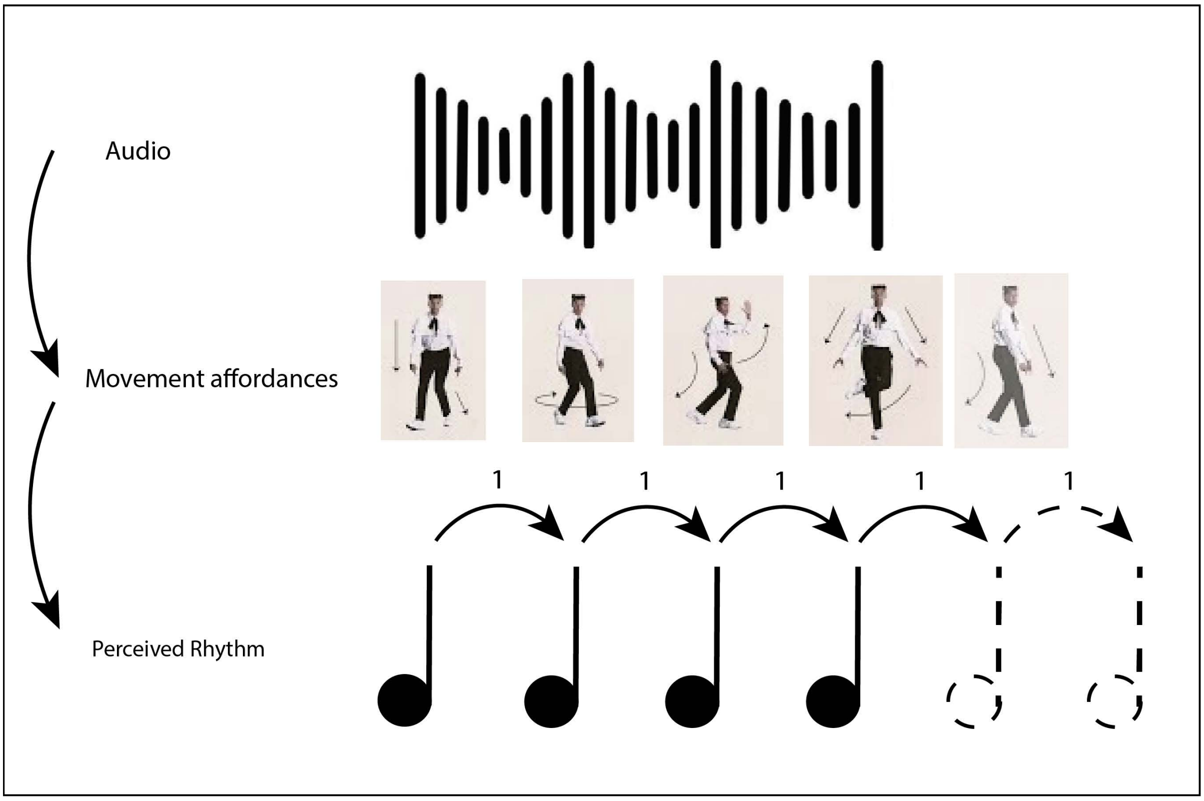


image / figure 2: Visual explanation of affordances in rhytms

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

The effects of rhythmic entrainment are valuable for our society; it helps us connect to our emotions, bodies and other people. Unfortunately, the applications in products are limited to a few industries. Designers should apply the theory in much broader cases. To achieve this, more knowledge on the interaction between the user and rhythm needs to be generated. A few questions will be explored: What is rhythmic entrainment (factors&effects)? Which products/industries use rhythmic entrainment? What can rhythmic entrainment as affordances for movement teach us about the desired interaction? Which factors influence the interaction between audio and haptic vibrations? The first two questions explore the possibilities and limitations (viability & feasibility). The last 2 dive deeper into the desirable interaction between the user and the rhythm.

A literature review will provide the first outlines for answering the questions. To get a deeper understanding of the interactions, interviews are held with 4-6 professionals in music: (interpretative) dance, (live) DJs, musicians/producers, sound technicians, etc. A benchmark of multiple (3-4) products that use rhythm will help understand the design choices, current interactions and technology limitations. A creative session is organized with 2/3 professional designers. The insights of the previous activities are shared and the designers are asked to create product ideas with the theory provided to them.

Finally, the most usefull insights about the theory can be written down as design principles, 1-2 principles are used in a research through design case with Glimp meditation tools.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

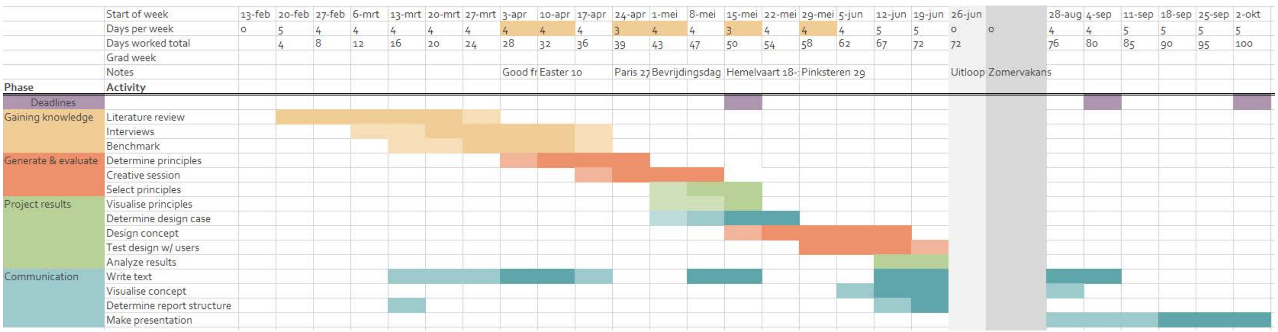
Guidelines for creating intuitive interactions between users and rhythms in products, used to amplify the effects of the Glimp meditation tool.

Generating knowledge and providing it in a practical manner for designers e.g. through an infographic. This knowledge will be used to research a desirable user-rhythm interaction through the (re)design of a new feature of the Glimp meditation tool. The tool itself will not be (re)designed, but the haptic vibrations and audio will be altered.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 20 - 2 - 2023 | 2 - 10 - 2023 end date



I'll reserve the mornings for activities such as literature reading and writing text. The afternoons are used for interviews, image/model making & contacting people. My planning is a more detailed gantt chart, where I can find the tasks for each week, each morning I'll spend some time scheduling ahead for the day.

Initials & Name ______ Student number ______

Title of Project ______

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

It frustrates me that rhythmic entrainment isn't used as much in products, even though it can truly help people get out of their head and into their bodies. Embodied interaction is paving the way for products that take the body into account, which I think is a good place to start. Music is a perfect example of how it works. I experienced how music can get me out of my head and into my body and I want to share that experience with as many people as possible through my work as a designer.

I want to research directions I never adressed during my masters; embodied interactions and rhythmic entrainment are entirely new to me. With this thesis I aim to connect 2 topics I don't know much about with 2 topics I'm passionate about (music & design), this will show my integration skills on larger topics than product design.

I also like to dive into a new theory, taking the time to understand it. During my master degree we never had time for this, as we were always designing products. Academic analyzing and writing is thus something I still have to learn, especially when taking the time constraints into account. Estimating time will be an active part of my thesis planning, so I'll have a better view on how long activities take.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.