Tools for Mindful Timekeeping
4 Devices to Change Our Relationship to Time

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Abstract

This thesis presents an investigation into the development of a series of devices that alter our relationship to time. The intention behind each of these devices is to help people become more aware of the temporality that is at the core of our being.

Time pressure comes from the networks of timekeeping that surround us. It’s not just our clocks and watches. Time is synchronized across devices, cities, and continents. Networked time regulates our lives today more than ever before. Modern timekeeping has shaped our culture into one that squeezes productivity out of even the most inconceivably small time increments.

Time was once kept at a distance. Church towers and grandfather clocks marked time in space. As technology advanced, timekeeping has shifted inwards and closer to our bodies. Time is embedded in watches, phones, and every digital electronic device that surrounds us.

Today, fewer people wear watches and keep time for themselves. We've outsourced our sense of time to systems that we don't understand. Our phones and computers display time accurately without intervention or maintenance, making watches seem redundant. Those who are less aware of time are surrendering to an unfamiliar force. They invite environmental pressures to pull their sense of time away from an innate internal awareness towards a grossly distorted sense that views time as a commodity. Modern timekeeping might help with efficiency, but we are busier today than ever before.

While we've shaped our temporal perception through the increasing precision of standardized time, human psychology remains connected to time, but not congruent to the physics of it. If we can become more aware of our relationships to time, we can manage our expectations and counteract temporal illusions, misperceptions, and distortions.
The devices presented here call for a more mindful approach to timekeeping. Rather than pushing time into the periphery, I hope to empower people to make time their own. We can challenge the temporal pressures of our environment, culture, technology, and state of mind through an alternative relationship to time.

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1. Introduction

1.1 Motivation

Time is power. The British colonial empire ran wires around our planet to synchronize their clocks even before we had electricity to power lights. This superimposition of Greenwich Mean Time (GMT) shifted time from the realm of metaphysics to coordinated signals¹. We now live within an exogenous temporal landscape.

Most of the world abides by GMT, a regime we’ve lived under for the last 130 years. This has enabled social coordination, travel, communication, and countless other enhancements to civilization that are taken for granted every day. But for all the affordances that timekeeping provides, we choose to wear tracking devices that we maintain ourselves to keep in sync with home base.

Greenwich Mean Time, telecommunications networks, and machines manage and govern global time. Time is not ours.

I’m interested in finding alternatives that return ownership of time to individuals. Acts of timekeeping should be active rather than passive. Perhaps people were more mindful and aware of time when timepieces needed to be wound by hand each day.

Time was once a human scale of measurement. Increments smaller than a second didn’t exist. Beyond simply standardizing time, the act of measuring and keeping time has accelerated time. Julian Bigelow once told George Dyson, regarding computation, “Sequence is different from time. No time is there.” Digital technology will run its sequences as fast as the hardware permits. As the digital world continues to increase its clock rate, the divide between human time and electronic time expands.

Today, we measure computing cycles and network communication speeds in nanoseconds and picoseconds. As technology gets smaller, faster and cheaper, more devices are operating at gigahertz frequencies. As new technologies become essential tools for living, our temporal landscape gets progressively subdivided. The world is increasingly measured in increments that live outside of human perception.

This thesis seeks to make time our own by creating new devices that provide alternative relationships to time across a wide range of durations. The primary focus in developing these devices is to create

experiences with sufficient delight to motivate users, rather than a set of consumer gadgets, utilities or lab experiments. Each device has its own set of desirable effects, but have a common goal of reframing how we understand time and providing an alternative relationship to time.

This work is important as it reframes our sense of time as plastic and tunable. If the devices are engaging and show that they can alter our sense of time, we can begin to investigate repercussions they may have on brain function, motor coordination, and as yet unexplored temporal relationships within ourselves and among social groups.

1.2 Overview of Thesis

The remainder of this thesis is organized into 5 chapters.

Chapter 2, Background, is an overview of time perception modalities that have been established in the field of time perception research. Many experiments have been conducted on human time perception that reveal distortions of our internal sense of time. Relevant research in this area provides insight into the latest understanding of how we perceive time.

Sources of internal oscillations in humans and other living things are still mysterious. We have little evidence that points to a portion of our brain, or an environmental oscillation that resonates with our internal sense of time.

The Background chapter outlines the ways in which we measure time perception, the probable causes of time distortion, cultural relationships to timekeeping, and experiments in time perception.

In Chapter 3, I present new work that support this thesis. Each of the 4 devices has its own background section and conclusion as well as technical and design sections that describe how the devices are built and the intention of the device. Each section in this chapter includes an evaluation that describes how the successes and failures of the device is evaluated.

Chapter 4, is the overall conclusion of this thesis.
1.3 Summary of Contributions

The primary goal of this thesis is to develop a series of engaging and desirable devices that provide alternative relationships to time. With respect to this goal, each device has been implemented beyond a proof of concept to consider questions around distribution and manufacturing. The following are the contributions of this thesis.

1. A survey of alternative timekeeping devices
2. A survey of time perception experiments that reveal our latest understanding of how we perceive time.
3. A design case study for building simple games to increase internal timing
4. An iOS framework for displaying and reading user input with high temporal fidelity.
5. A design case study for collecting isolated data from game interactions
6. An open source hardware platform for developing custom ARM-core based wrist worn devices.
7. Engineering and design case study for a battery powered device built to work continuously for over 100 years
2. Background

Time perception is a fundamental component in our ability to build mental models of our world. Without accurate and precise time perception, we might have trouble understanding speech, fumble social interactions, or even hallucinate\(^2\).

Our brain can stitch phonemes into words and words into sentences and sentences into meaning because we can parse the order and timing of what we hear. We can shake hands because I can predict how your hand is going to move and I can time my movements to meet yours at a desired location. When I speak, I know I'm hearing my own voice, because the sound and my thoughts are carefully synchronized by my brain.

Critical timing events work flawlessly and continuously for most of us, creating the illusion that incoming signals from our senses happen at the same time, even though they are often phased. We take all of this for granted until we stumble. In some cases, our brain decouples signals so that our own voice sounds like someone else is speaking, or we lose motor control, or misunderstand language. Schizophrenia may be caused by timing misalignments in the brain.\(^3\)

For neurotypical individuals, timing at this scale operates as intended. Sub-second latencies in brain signals or even latencies in our interaction with devices are seamlessly edited out of our awareness. But, most of us have observed phased timing or time distortions at larger experiential scales.

When we speak of time distortion, we often cite high adrenaline, near-death experiences, where it felt like time slowed down. The Eagleman Lab has shown through a novel experiment that involves a free fall amusement park ride, that time doesn't slow down, but instead, time in our memory is distorted\(^4\). Subjective time and memory are inextricably linked. Time is perceived through memory.

By distilling time perception into its fundamental principles, we can tease time away from memory and focus on our internal sense of time. A few key inspirations along with my previous work in building

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timekeeping devices evolved into an investigation of a new set of devices for altering our relationship to time from sub-second to decade long durations.

### 2.1 Measuring Time Perception

> "Time perception matters because it is the experience of time that roots us in our mental reality. Time is not only at the heart of the way we organize life, but the way we experience it." 

Although temporal measurement is absolute, our perception of time is subjective. Timekeeping devices today synchronize with a master clock with atomic accuracy and chip-scale atomic clocks are on the horizon. Any synchronized timekeeping device is displaying time with an accuracy of $10^{-9}$ seconds per day. In other words, the clock's accuracy might drift up to 1 second after 30 million years. Meanwhile, time can be distorted by minutes or even hours when we consciously attempt to keep track of it internally. On top of that, we commonly miscalculate the timing of past events by months or even years. Age, drugs, emotional state, and even body temperature affect time perception.

Time isn't a sensory input, in fact, we don't actually sense or perceive time the same way we smell, taste, hear, see, or feel. Instead, we use our five senses to observe changes or the duration between events. In order to deduce or "sense" time, we rely on our memory rather

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Although our perception of time relies on other senses, we can break down and measure human time perception as its own fundamental entity.

Human time perception can be measured in 4 primary methods\footnote{Friedman, William J. Psychological Bulletin, Vol 113(1), Jan 1993, 44-66.}.  
1. Duration estimation: ability to estimate a stimulus duration.  
2. Duration comparison: ability to differentiate two different stimuli.  
3. Duration reproduction: ability to observe a stimulus and reproduce the duration of the stimulus.  
4. Duration production: ability to produce a specific duration.

It is through these primary methods of measurement that we are able to conclude that time perception is subjective and often misaligned with absolute time.

### 2.2 Endogenous Time

The standardization of time has built expectations of how time is experienced. Universal Standard Time is applied and understood across languages and cultures. Time is treated as a finite resource or a form of currency, even though each individual perception of time can vary greatly.

Age, fear, mood, and a long list of environmental and internal factors are known to contribute to the mismatch between internal time and absolute time. Our consciousness is fundamentally linked to how we perceive time.

Perception only happens in the present. What is perceived is only true at that moment. Once that moment has passed, only a recollection of that memory can reconstruct the experience. Any reconstruction of a memory is temporally distorted.

Below are 6 types of subjective experiences where time is distorted internally.

Many people report that time slows down during life-threatening events. Thoughts bubble up at a super-human speed and things move in slow motion.

Tse et al believe that a shift in attention is what creates the illusion of time acceleration. Their internal “counter” model hypothesizes that we all have an internal beat at which we process information. If we expect to process one bit at a regular rate, but suddenly are processing two bits because of a heightened state of awareness, we may perceive that time had slowed down.

In other words, our senses go into turbo-boost, recording more information than we are accustomed to, and therefore assume that time changed.

The Eagleman Lab conducted an experiment in a freefall amusement park ride to see if a life-threatening condition would induce a higher sensory framerate. The experiment had subjects dropped onto their backs from a height of 150’ onto a safety net. Strapped to the subject's arm is a display that shows 2 digits that are flickering too fast to see by human eyes under normal conditions. The subjects are then asked to look at the display during freefall to see if they can make out what 2 numbers are displayed. If the subject's sensory frame rate increases, they should be able to make out which 2 numbers are displayed.

None of the subjects in this experiment were able to make out the numbers, but when asked to recall the experience of the freefall by timing the experience with a stopwatch, the 2.6 second duration was recalled to last longer than 4 seconds.

Our memory is being packed with information from new and shocking environments which are then recalled later to give us the illusion that the event lasted for a longer period of time. Our time perception stretches when our memory contains more information than we normally record.


Studies have shown that seemingly innocuous factors such as rapid eye movements and adaptation to flickering or moving stimuli also distort time judgements.  

**Consciousness is 80 Millisecond Delayed**

We're constantly living in the past. Our consciousness is 80 millisecond behind the actual event. Everything we experience has already happened. It's within this 80 milliseconds that our brain synchronizes signals for us. That's why an audio track for a movie with up to an 80 millisecond delay will still seem perfectly matched with the screen. Our brain edits the two slightly phased signals and matches them perfectly.

The brain is constantly adjusting and synchronizing events to make sense of the world. Like a real-time video editing studio, the brain is stitching together a scene for the conscious. In this editing process, lots of snippets are left on the cutting room floor. In another experiment by the Eagleman Lab, they show that a slight shift in timing causes a temporal order illusion.  

Subjects were asked to press a button to make a light blink with an artificial delay. After some time, the subject becomes accustomed to the delay, experiencing the light blink as soon as the button is pressed. When the delay is suddenly removed, subjects reported that the blink happened before they pushed the button.

All human computer interfaces have latencies that are often just below the 80ms threshold of our brain's auto editing. These edits can become so hardwired that they are imperceptible even if you know your perception is being edited. Try looking at your eyes in a mirror. Switch from looking at one eye to another. You will never see your eyes move. Watch someone else do the same and, you'll see their eyes are clearly moving.

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Awareness is up to 10 Seconds Delayed

Libet’s life work focused on understanding the timing of signals in the brain. In a landmark study, he found that our awareness of an event trailed 0.5 seconds behind the neural signals of the event reaching the brain. He refers to this 0.5 second delay as Mind Time. 19

Take for example the experience of tapping your finger on a table. Libet’s findings show that even though the detection of signals may be immediate, your awareness of the event is up to 0.5 seconds delayed.

Signals that travel in the opposite direction also appear to be delayed. In his experiment he had subjects move their wrist whenever they wanted. They would note the precise time when they decided to move. These recordings showed the decision to move happens 200 milliseconds before the movement.

Libet also measured the readiness potential from the supplementary motor area of the brain. Readiness potentials precede the subject’s awareness of the decision to move by 350 milliseconds.

Libet has recorded similar results with speech, showing that the content of speech must be generated unconsciously before speaking begins.

In more recent findings, using fMRI, scientists found decisions are encoded in brain activity up to 10 seconds before the subject is aware of the decision he or she is making. 20

Peripheral Vision has Temporal Blur

The brain is subject to temporal blur. There are things that happen at speeds that our vision cannot perceive. The brain does an amazing job at stitching together a world that makes us believe we can see everything around us, but our visual perception is quite narrow and unfocused.

There are two types of temporal blur. One type of temporal blur makes fast motion like a speeding car appear blurry or the flickering of a computer screen appear smooth.

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There's a second type of temporal blurring due to the eye's narrow focus.

There was a time when we didn't know whether horses lifted all their legs when they trotted or galloped. It wasn't because a horse's leg moves too fast to see, but rather, it's impossible to focus on all legs at once to see if all legs were off the ground at the same time. Our vision has a deceptively narrow focus. At any moment our eyes take in only a small slice of our overall vision. The rest of our peripheral vision is blurry at best and lacks color, motion detection, and shape detection. Hence, our inability to see and comprehend the state of multiple fast-moving objects at once.

Well Being Depends on How We Reconsider the Past

Try this thought experiment. "Consider two different lives that you might live. One life begins in the depths but takes an upward trend: a childhood of deprivation, a troubled youth, struggles and setbacks in early adulthood, followed finally by success and satisfaction in middle age and a peaceful retirement. Another life begins at the heights but slides downhill: a blissful childhood and youth, precocious triumphs and rewards in early adulthood, followed by a midlife strewn with disasters that lead to misery in old age. Surely, we can imagine two such lives as containing equal sums of momentary well-being.

Yet even if we were to map each moment in one life onto a moment of equal well-being in the other, we would not have shown these lives to be equally good."

.....The reason why later benefits are thought to have a greater impact on the value of one's life is not that greater weight is attached to what comes later. Rather, it is that later events are thought to alter the meaning of earlier events thereby altering their contribution to the value of one's life.  

We can redeem past misfortunes in one's life. We gain life lessons from childhood misfortunes, but given a choice, a child would be hard pressed to suffer now for a better life in the far future.

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The way we remember our past has a direct influence on our happiness and well being. Is a life of well being a life of improvement? an uphill battle?

*Time Flies When You’re Having Fun*

Claudia Hammond refers to the phenomenon where the time while on holiday seems to pass quickly, but feels like it lasted much longer afterwards as the ‘Holiday Paradox’. Much like an extended version of the free fall experiment by the Eagleman Lab, new environments are stimulating and cause an influx of new information to be recorded. When our memory is played back at a later moment, the time seems stretched because we have more information to recall than we are accustomed to.

Can we control time perception by exploiting the Holiday Paradox?

### 2.3 Our Relationship to Time Through Timekeeping Devices

The overall ethos has been to try to make external time keeping increasingly precise and stable. Right now, the accuracy of the NIST-F1 Cesium Fountain Clock holds the standard for timekeeping in the United States at an accuracy of $5 \times 10^{-16}$.

Many household clocks and watches today synchronize to an atomic clock via broadcasted time signals, but advances in technology will soon make grain sized atomic clocks available for any electronic device. The ways we keep time overrun our lives. The ways we meet, work, sleep and enjoy life have been encroached with time increments that are now imperceptible.

Our society is getting less synchronized as technology built under the guise of productivity, enables communication, work and play to happen asynchronously. We no longer watch TV and movies together, we communicate asynchronously over email and text messages, and work from anywhere at anytime. We are losing

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24 Cesium clocks work by constantly tuning and adjusting a microwave signal as close as possible to cesium’s stable resonant frequency of 9,192,631,770 cycles per second. ("NIST-F1 - Cesium Fountain Atomic Clock." NIST: Time and Frequency Division - Division 847. 5 May 2009 <http://tf.nist.gov/cesium/fountain.htm>.)
our ability to see and feel the time pressures around us and at the same time, we are phasing out of sync with each other.

We've strayed far from our biological clocks. We sleep and play around our work schedule and a few seconds of attention focused on a smartphone now qualify as a productive moment. Every split second demands productivity, speed and efficiency. Each introduction and adoption of smaller time increments promote unprecedented shifts in our understanding of a productive moment. It's telling that when we used to ask for someone's time and attention we'd ask them if they had a minute to spare. Now we ask if they have a second.

Modern timekeeping begins with the Benedictine Monks. They believed they were on Earth to do God's work, so their time on Earth was to be productive. They built one of the world's first mechanical alarm clocks. A bell would signal a shift in duties. Cleaning, praying, eating, or whatever it might be, the bell signaled a change in activity.

Soon after the bell came some of the first mechanical clocks, built for religious purposes. These were large weight driven clocks in clock towers that indicated time with only an hour hand.

When pendulum clocks were invented, timekeeping precision increased significantly and began to find its way into domestic settings. Miniaturization and precision became indicators of quality as the domain of timekeeping spread from religion, to fashion, and navigation.

Timekeeping accuracy has a direct correlation to the accuracy of determining longitude at sea. This seemingly narrow utility of timekeeping provided the initiative and motivation to develop extremely accurate timekeeping devices, starting with the Longitude Prize in 1714. We continue this tradition as GPS, time-of-flight cameras, high bandwidth communications, and countless other technologies rely on greater accuracy and precision. As of April 21, 2015, the experimental strontium lattice clock at JILA is precise and stable enough to deviate less than 1 second in 15 billion years (the approximate age of the universe). This level of precision is great enough to measure change in relativity as the elevation of the device changes just a few centimeters.

25 The English word clock is derived from the Middle Dutch word for bell, klocke.
26 Longitude rewards offered by the British government starting in 1714 were the first longitude rewards to be collected. Spain offered one in 1567, among others, but these were never won.
The introduction of the crystal quartz watch in 1992 marks the beginning of a new era for timekeeping and digital electronics. Today, ICs like the Maxim DS3231, cost $5 and have an accuracy of ±2 parts per million. Accurate clocks and oscillators are now found in every digital device and have far reaching effects like the synchronization of the AC power grid or the 60Hz hum of your refrigerator to global panics like Y2K.

The wildly subjective inaccuracies of the human experience of time is at odds with the increasing precision of regulated clocks. People are aware of this trend, yet unequipped with tools or technology to adequately respond.
3. Devices to Reframe Time

For this thesis, I've built 4 devices to help counteract endogenous temporal distortions and reframe our relationship to exogenous time.

Time is ubiquitous. From the few milliseconds it takes or the brain to process signals into awareness and the years of memory that we're able to recall, we rely on precise and accurate timing. We take time for granted, with little regard to how our sense of time is fundamental and indispensable.

We keep track of time to coordinate meetings, measure durations, calculate speed, and geolocate, but most importantly we keep time to situate ourselves in time. Much like the comfort of knowing where we are in space, we also like to know when we are time. How old am I? How long has it been since I moved here? How much longer until Spring?

Timekeeping devices provide a measure in time much like a ruler for length. But our current relationship to time is one that is like a tracking device. We are kept by the time displayed on our devices. The only people that keep time are master timekeepers like Demetrios Matsakis who runs the Time Service Department at the US Naval Observatory. He's in charge of handling leap seconds. Matsakis keeps time and the rest of us are kept by the time he keeps.

Stopwatches and timers are interesting devices because they adhere to common timekeeping units (seconds, minutes, hours), but are individually set by a user. They allow for individuals to be their own master timekeepers.

The following sections describe the 4 new devices that were created for this thesis. Each device is preceded by its own background section that outlines related work. The section ends with a contributions and conclusion sub-sections.

The intention behind each device is to help us become more aware of the temporality that's at the core of our being and provide an alternative relationship to the ways we keep time.

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**MA-6 Timer** is a wrist worn device to provide alternative timekeeping modes with a primary focus on setting your own time increments to divide your day.

**Time From Launch** is a pair of single use long scale stopwatches for two people to create and maintain their own time meridian over the course of a few decades.

**Tempra** is a mobile app to test and increase your ability to produce specific durations from 0.5 seconds to minutes.

**Darkball** is a mobile app to test and train your sensory motor coordination and duration reproduction accuracy and precision.

### 3.1 Device 1: MA-6 Timer

**MA-6** (named after John Glenn’s historic Mercury Atlas Mission) is a new digital device dedicated to actively setting timers from minutes to hours for a more mindful relationship to time.

Time increments from 1 minute to 24 hours can be easily set through a physical knob interface. A vibration is activated on a selected time increment on a loop. So if the timer is set for 15 minutes, a vibration will be activated every 15 minutes. A user attempting to internalize what 30 minutes feels like would set the timer for 30 minutes.

At each alert, the user is encouraged to reflect on where he or she was the moment the last alert was activated and remember what has happened since then. This mindful practice of reflection and active engagement could help align our subjective time to reality, building towards a more accurate model of both human time and machine time.

Most timepieces today are primarily a tool for tracking time in relationship to Coordinated Universal Time (UTC). We've conveniently drawn artificial boundaries of time to group countries and subregions to coordinate populations. UTC based clocks are so common that we think of it as a convention or a utility. But let us not forget, that it is a form of control as the British colonial empire clearly understood it. Greenwich Mean Time (GMT) was established in 1675 and by 1929 almost the entire planet adhered to

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29 All of China and India today use a single time zone even though the each country’s width far exceed the nominal 15° longitude. 360°/24 hours = 15° per hour
a standard offset from GMT. Nepal was the last to join, adopting a unconventional (non hourly) UTC+5:45 offset in 1986.

We often speak of not having enough time or needing more of it. People are bound to time and their ability to manage time. Could people improve their well being by learning to become more mindful of time?

Personal well being is tied to how individuals manage and speculate on the time available within a day. A device dedicated to promote mindfulness of time could help internalize our sense of time and decrease time management related stress.

3.1a Background

Wearing a watch doesn't necessarily strengthen your internal sense of time. But a device with a feedback loop could increase our awareness and mindfulness of time. The following are precedents that attempt to alter our relationship to time through a feedback mechanism.

*Durr* by Skrekkogle, is a bracelet that vibrates every 5 minutes to create a haptic rhythm to create an awareness of the changing tempo of time. The device has a single pushbutton to turn it on or off. While this gives a consistent and passive marker to time, it lacks user input to customize the duration to an appropriate length and to activate a stronger sense of commitment and engagement.

*Tictoctrac*, by Brian Schiffer and Sima Mitra, is a time perception tracking project that uses a custom watch to gather data about when the user checks the time, the accuracy of their estimation of the current time, and accuracy of short time interval trials. The system provides a great starting point to gather data about human time perception, but lacks feedback and a robust interface to alter the user's time perception.

There are several existing mindful timekeeping practices that I've grown to appreciate and continue to practice. These are small habits have changed the way I work, play, and remember my days.

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The Pomodoro Technique, first introduced in the 1980s\(^3\), is a simple and powerful working method that has been part of my personal routine for the past two years. The technique is simply, 25 minutes of focused work and a 5 minute mandatory break. This 25 + 5 minute cycle is called a Pomodoro. The power of this method is that it breaks a day into mentally digestible chunks so I can begin to predict how many Pomodoros are available in a day or how many Pomodoros I might allocate to a specific task. This approach counteracts time related stress and time distortions that might be associated with a boring or eventful day.

Timeful is a calendar and scheduling mobile app by Jacob Bank and Dan Ariely that places items from your todo list into your calendar\(^4\). The idea is to put anything that competes for time in one place, so you can account for your time in a more realistic manner. From the app's perspective, ideally, everything from writing a birthday card to office meetings would live in one place, but the reality is many things can't be scheduled or aren't worth the effort of entering it into the system.

These practices are simple and empowering, but are focused on productivity. The Pomodoro technique has a primary goal to make us all productive workers and Timeful finds any opening in your schedule to automatically slip in another task, packing the day to it's maximum capacity. MA-6 is concerned with a human centric sense of time rather than a machine centric sense of productivity.

3.1b Design and Engineering

The device produces passive alerts through a vibration motor to encourage reflection throughout the day to make each day more memorable and in turn counteract day-scale distortions of memory and time. An uneventful day spent driving on a highway could be made as memorable and feel as long as a walk in a new city by triggering milestones throughout the day. By empowering the user to set their own time intervals, this simple act changes time from a passive flow to an active reach.

The watch display doesn't display UTC time. Much like Glenn's mission elapsed timer on the Mercury Atlas-6 mission, the device encourages each day to have it's own beginning that's activated by the user.

\(^3\) Available at: http://pomodorotechnique.com/. Accessed April 22, 2015.
The physical design features a large knob as the user interface. The knob is a rotary encoder with detents and a pushbutton. This tactile interface was chosen to quickly and easily set timers. Traditionally timers of this kind in digital watches are set by pressing or holding down buttons. A knob is preferable because you can spin to increase or decrease durations at various speeds and increments more intuitively.

The screen below the knob is an ultra low power LCD memory display. The device runs on an ARM core chip allowing robust applications to run at high speeds. A vibration motor is used for silent notifications.

MA-6 is built upon the work of many open source projects, so the hardware and software is open source. The micro USB interface is provided for recharging and programming through the Arduino IDE. This allows for a large community of makers to write code to customize the device down to the firmware level.

The default software running on MA-6 features an easy to set timer loops that encourages users to time everything. Included in the default configuration is an abstract clock interface that displays the Sun in relationship to the horizon based on your current location and time. The idea behind this display is to bring the viewer's attention to the Sun's relationship to Earth, rather than displaying the exact time relative to an UTC base time zone.
The Moon interface displays a similar concept. The view shows Earth and its relationship to the Moon and the Sun, so it becomes clear where the Moon is, how much of the Moon is bright, and why.

3.1c Contributions

The chief contribution of MA-6 is an open source hardware platform for alternative individual (as opposed to collective) timekeeping. To encourage alternative uses, I've written a few examples of ways I imagine myself using the watch. Over time I hope to see others write novel interfaces and build upon the hardware to change the way we think about and occupy time.

Included in the work of MA-6 are contributions to hardware design through a new approach to watch case design, manufacturing and assembly.

The physical case of the watch is made of two parts that slot into each other while holding all the inner elements in place. The entire assembly is held in place with a single screw. The design is 3D printable without support material on a consumer FDM printer.

The different views on MA-6 are navigated through a menu interface that's controlled by a rotary encoder with a push-button. The software written for MA-6 relies heavily on libraries built by
others in the open source community. All the additional code written for MA-6 is open sourced.

3.2d Evaluation/Conclusion

In total, 6 working prototypes so far have been built to develop MA-6. Each prototype builds upon the work of the previous, whether it's the physical design, miniaturization of the hardware, interface design, or improvements to power management.

It's important to acknowledge the proliferation of smart watches on the market as devices like Pebble and Apple Watch have entered the mainstream. MA-6 doesn't have features that can compete against devices built by large corporations. Rather, MA-6 is an alternative development for alternative modes of timekeeping.

The physical interaction of the device is inseparable from the experience, therefore, this watch was built from the ground up.

First and foremost, MA-6 needs to function beyond a proof of concept with a design and build quality that surpasses user's expectations. Based on an anecdotal assessment, there's strong interest from the public for a device like MA-6. Although people are quick to point any smartwatch-like device is cumbersome because it requires intermittent charging. The attraction seems to be in its design aesthetic rather than its function which could be an indication of a design direction that resonates with people.

MA-6 is an open source hardware project, allowing anyone to extend the hardware and software features to build a smart watch that does something no other smartwatch does.

Further development of the device will continue towards a fully functional prototype comparable to what would be sold in a retail environment. New devices by others, built on top of the open source work of MA-6, will be developed in tandem.

3.2 Device 2: Time from Launch

Time from Launch is a new hardware device designed and engineered to mark a moment in time by counting from that moment up to 1 million days.

When John Glenn went into space and became the first American to orbit Earth, the only piece of technology he wore other than the
space suit itself, was a 12 hour stopwatch. While orbiting Earth, John Glenn crossed time zones every 20 minutes. NASA tracking stations across the globe synchronized their clocks with Glenn’s stopwatch creating an alternate time zone based not on Earth’s orbit, but of a man orbiting Earth. This simple act of setting a Mission Elapsed Time (MET) is powerful and empowering.

We use time meridians as markers in time from which we compare events that have happened since then and before that moment. Like an anchor in time, a time meridian keeps our reference of time situated and comprehensible.

We all have time meridians or time anchors that we use to compare events against. It’s often the birth of a child, the death of a loved one, or a catastrophic global event. Catastrophic global events like the Fukushima Daiichi nuclear disaster often serve as communal time meridians. These time meridians are set by fate.

Time from Launch is a device to create intimate time meridians shared between two people. The device itself is meant to serve as the event. So, instead of using the device to mark a special event like a marriage or a graduation, the hope is for two people to claim a random moment in time to mark as theirs.

3.2a Background

This new device lives somewhere between an art piece, consumer device, chindogu, and design fiction. There are many precedents and inspirations for this work some of which I will describe below. Countless others over the course of my life have contributed to the thinking and intentions behind the work.

Every NASA mission to space has a Time from Launch timer. It’s the same clock that counts down from 20 seconds to launch. Immediately after launch, the timer continues counting up and becomes the backbone of all the communications and mission sensitive components. Time from Launch for space missions is important enough that there are several backup timers on the wrists of almost every involved, including the astronauts.

The 10,000 Year Clock, designed by Danny Hillis, is an ambitious project to build a clock that will keep time for 10,000 years. To build a mechanical device that is meant to last that long, unusual circumstances need to be considered. For example, metal gears may fuse together into a single piece in as little as 5000 years, so some parts need to be made of stone or ceramic. This project invites
all parties involved to think beyond the immediate now and far into the future millennia beyond our lifetime.

*Untitled (Perfect Lovers)* by Felix Gonzalez-Torres is two store-bought clocks hung on a wall, touching, horizontally aligned, in sync, on a wall painted blue. This simple and powerful art piece references his love and time with his partner, Ross Laycock, who died soon after this piece was made. The clocks start with their second hands synced, but drift over time.\(^3\)

In 1998, in a letter to Ross Laycock, he writes...

*Lovers, 1988*

Don't be afraid of the clocks, they are our time, time has been so generous to us. We imprinted time with the sweet taste of victory. We conquered fate by meeting at a certain TIME in a certain space. We are a product of the time, therefore we give back credit where it is due: time. We are synchronized, now and forever. I love you.

In 2002 Tobias Wong produced *Perfect Lovers (Forever)*, a seeming replica of Gonzalez-Torres' piece, but with one crucial difference. Wong's clocks use a radio clock movement that synchronizes to the longwave time signals that are broadcast in the USA from Colorado, keeping the two clocks perfectly in sync forever.\(^3\)

### 3.2b Design and Engineering

**User Interaction**

The pair of stopwatches are presented in a vacuum sealed bag. This ensures the device hasn't been tampered with and provides an extra seal against the environment while in transit and storage.

Once the seal to the bag is broken, the two devices turn on for the first time and produce a sequence of audible beeps to indicate the two have started counting in unison. From the moment the bag is opened, the two devices will remain in sync with an accuracy of 2 parts per million (maximum drift of 1 second every 5.7 days or about 1 minute a year) for as long as they are powered continuously.


Design

Significant time and thought has gone into prototyping and detailing the design of the device. Engineering and design constraints were considered in tandem to arrive at a decision for each screw, gasket, chamfer, IC, and material choice. The overall form is minimal and restrained to echo the visual language of industrial parts like something you might find at the heart of a time machine.

The device is housed in a thick glass tube to show all the components and electronics in a way that is transparent and legible. All the components from the display to the batteries are visible without opening the device. If replacement of a part is needed, parts can be sourced and prepared without disassembly.

The glass is extremely durable and capped with heavy aluminum parts with a double airtight seal to ensure dust or moisture is prevented from entering and corroding the electronic parts. The electronics are designed and built to be robust, but they are still delicate relative to the glass and aluminum housing, so the
assembled PCB is held like a biological specimen afloat in the glass tube.

Display
The display features an e-ink 12 digit readout, 6 of which are dedicated to displaying days elapsed, setting the maximum number of days that the display can show to 999999 days (approximately 2,739 years). The display readout format is as follows: ddddd hh mm ss (where d is days, h is hours, m is minutes, and s is seconds).

The e-ink display is rated for a work life of 50,000 hours, which translates to about 208,333 days if we assume a 1% duty cycle on the screen. In reality, the right-most digits (second, minute, hour digits) will be refresh more often than the left (day digits), so those will begin to degrade earlier than the left digits.

Power
To increase the potential life of the device, a photodiode is used to sense ambient light conditions. If there isn't enough light to read the display (for example if the device is placed in a drawer) the device will stop refreshing the e-ink display to save considerable amounts of power and duty cycles.

Magnet and Reed Switch
The packaging that holds the pair of devices in place has a an embedded magnet. Each device has a reed switch to detect when the magnet is removed. This type of single-use switch allows the device to remain totally sealed from the environment as opposed to traditional single-use tabs or seals that physically separate the battery from its contact.

Redundant Power
It's probable that every electronic device that we use today will become obsolete in the next couple decades, primarily because of technology's obsolescence. We design technology with the present and the near future in mind. Rarely does the the far future or 100 years into the future, have a voice in the design of devices today. There's not much craft in digital devices today, but I strongly believe it's an area people can appreciate the same way we appreciate a well designed instrument that continues to hold its value over centuries.

This mode of thinking and design is the primary force behind the design decisions and the engineering of the device.

To build an electronic device that runs continuously for 100 years, the primary concern is the continuous power supply needed to run the Real Time Clock (RTC). Several continuous power schemes were
considered. The following detail some of the feasible scenarios and conclude on one scheme for this particular case study.

**AC Power**
AC power (plugging it into the wall) was first considered because it's ubiquitous and relatively reliable. For any outages, a (replaceable) rechargeable battery would suffice. Although AC power is feasible, having to plug in and recharge a device, seemed counter to the idea of a device that may be needed on a moment's notice.

**Solar cell with rechargeable battery**
The desire to have the device be portable was quite strong, so using solar cells with a rechargeable battery seemed like a perfect fit.

Pictured to the right is a prototype with a solar cell, lithium polymer battery and a e-ink fuel gauge display to indicate the power level of the battery. The combination of all these components would culminate to an interaction that would be unintended but desirable. Once the stopwatch starts, the user would have to check the fuel gauge once every few days to make sure the stopwatch had enough energy to continue counting. If the battery is low, the user would have to find a strong light source to feed the device power.

This type of interaction was desirable as a way to remind the user and engage the user throughout the life of the device. Each "feeding" would be a moment to reflect on the time since the stopwatch started.

**Peltier Junction with Heat Absorption and Dissipation**
Although solar cells could work for the most part, peltier junctions were considered as an alternative. The peltier junction could harvest energy by collecting and dissipating ambient heat changes from a phase changing material like paraffin wax through a heat sink. Over the course of the day as the ambient temperature rises, the paraffin wax would absorb the heat and turn to liquid. At night the wax would release the trapped heat and turn back into a solid. All the while the peltier junctions would use the temperature difference between the paraffin wax and the ambient environment to harvest energy.

In order for this scheme to work, the size of paraffin wax and the associated heat sink needed to ensure power remains continuous through mild temperature changes, would be too cumbersome for a device of this type.
Due to the short lifespan of lithium polymer batteries and the relatively quick loss in capacity over time (20% per year), all continuous power schemes that involved lithium polymer batteries were ruled out.

*Redundant AA Batteries*
Many battery form factors were considered to make the device as small as possible. Coin cell batteries, for example would allow the device to be relatively thin. AAA batteries would also allow a thinner form factor while maintaining large energy storage. After considering and prototyping with many battery types, AA batteries were chosen for their availability and size.

AA batteries account for over 50% of battery sales today. It's been around since 1947, so the likelihood of AA batteries existing in the future, even if the cell chemistry changes, seems probable.

A device that uses AA also means it doesn't need light, heat, or any external source of energy that may be difficult to provide in a continuous manner.

All power sources are intermittent, so the choice to use AA batteries, was a balance between longevity, ease of use, aesthetics, energy density and predicted availability in the future.

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Redundant power RTC test board.
The 1.5V AA batteries are each individually boosted to 5V to power the circuit. This configuration will last 7 years (due to the battery's shelf life) without replacing the battery.

To ensure continuous operation during battery replacements, the device relies on two AA batteries. One battery is the Main Battery and the other is the Backup Battery. The Main Battery powers the RTC, microcontroller unit and the display, while the Backup Battery is only enabled if and when the Main Battery loses power. The Main Battery can power the device for over a year on its own, and the Backup Battery can power the RTC for over 10 years.
In an attempt to understand how people might use Time from Launch, I built timesincelaunch.com, a webapp that's a single use stopwatch. Users enter a short description of an event they want to record, and press start. The webapp provides a permanent URL that will always show how many days, hours, minutes, and seconds have elapsed since that moment in time. So far, people have used timesincelaunch.com to primarily keep track of projects and life events.

3.2c Contributions
The most important contribution of Time from Launch is the example it provides for designing and engineering electronics to run continuously for over 100 years. Although there are constraints that won't allow for the idea to be fully tested, the implications of building electronics with the explicit intention to have it continuously run for 100 years sets new constraints on the design process that I've outlined above.

I hope the ideas embedded in this device, if not the device itself, resonate with people looking for an alternative relationship to time. The idea of setting and controlling your own time meridians is an important step towards a more individual and personal relationship to time. To know that time can be kept without being kept by time is a change in perspective that is healthier and worth pursuing.
3.2d Evaluation/Conclusion

The concepts behind Time from Launch have a certain resonance with people. Everyone I speak to immediately thinks of an occasion that might be appropriate to start a single use stopwatch. The enthusiasm is great and welcome, but the idea of creating and actively setting a new time meridian is often missed. Time from launch can mark an already special occasion like the birth of a child, or the beginning of a job. But, events of that sort are already important. They've made their mark in time and in memory by the forces of fate and luck. The power in Time from Launch is in setting a new time meridian as an act in itself. People can establish and claim a moment in time (a moment that is important because the device marked that moment). This may be the single most important act around the device, yet it's easily missed. Perhaps that's telling of how we are all kept by time.

3.3 Device 3: Tempra

Tempra is a casual stopwatch game intended for players to test their internal sense of time. It's built to be competitive. Players are motivated to practice and beat their own high score, scores of friends and scores on the global high score list.

Our internal sense of time is subjective. It is localized by our culture, swings with our moods, and is affected by body temperature. But time is absolute. One second, since 1967, has been defined as the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium 133 atom. If we handed out stopwatches to a million people and asked them to intuitively time one second, where would we land? What would the average be? the median? deviations? We all know what we think one second feels like, but do we know how accurate that feeling is? What is a human second as opposed to an atomic second?

Tempra encourages users to train their internal time production in sub-second to minute long durations. It's a lightweight casual game that's very much like a stopwatch, except you can't see the numbers. To play you must rely on your internal sense of time. The goal is to get as close to a given time increment as possible. Each level in the game increases in difficulty by lengthening the duration you have to model in your head. Each trial of the game requires greater

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concentration, encouraging you to deepen your inward focus and continuously sharpen your internal sense of time.

Practice, like with any other skill, yields higher accuracy. However, we don't know if accuracy is generalizable. For example, if your sense of two seconds is super accurate, does that also mean you’re good at dodging traffic?

We also don't know if time production is a skill that you can exercise like a muscle. Can you strengthen that muscle? Probably. Does it atrophy if it isn’t exercised explicitly? We don't know. If internal time production is a muscle that you can exercise, and if exercising that muscle has generalizable attributes, then practicing with Tempra may have profound effects on your health and well-being.

To gain insights into how our brain distorts time and generates biases towards time production, Tempra anonymously collects data from time production trials of players around the world. We won’t know unless we try. This is the beginning to an active investigation into how time is experienced.

Tempra is available for download on iOS devices at http://bit.ly/tempra-app

3.3a Background

Counting to 10 seconds might seem trivial, but studies have shown that environmental conditions like body temperature and emotion affect our internal sense of timing.

TicTocTrac is a watch-like device by Brian Schiffer and Sima Mitra that takes user input to track changes in time perception. The device displays a random time interval for the user to produce, then displays and records the difference. This mode of user input requires users to form a habit around the new activity, which may be hard to form without a clear objective or reward.

10 Second Stopwatch Game is a simple folk game that involves a regular stopwatch. The goal of the game is to stop the stopwatch as close to 10.00 seconds (but not over 10.00 seconds) without looking

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at (listening, or sensing) any timers. This game is fun to play, but repeated play likely trains players to have a strong internal time bias towards 10 seconds.

Every Second Counts by Ze Frank is a game that challenges player to produce time increments with 0.1 second accuracy. This web app captures the essence of an absolute time production task into a game-like activity, but is missing features to provide feedback to keep players informed of their progress and mechanics to keep players engaged over long periods of time.

3.3b Design and Engineering

The interface features an oversized readout of the target duration and the elapsed duration below.

After each trial, a series of messages pertaining to the performance of the trial slide in from below. To keep the game on pace, all animation elements happen very quickly (less than 0.4 seconds).

The game is broken into a series of stages that act as game save points when the game is over. Starting from a save point costs points which can be accrued by playing trials with accuracy.

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3.3c Contributions

As of this writing, over 156,000 data points have been collected from the general public. A thorough analysis is yet to be conducted, but a quick survey of the data reveals a bias towards inaccuracies at integer durations, while durations in between deviate less from the target. For example, the 5 and 10 second target durations (X-axis) have several points in the Y-axis (accuracy offset) that go beyond ±1 second, while values in between 5-6 show smaller deviations.

This finding seems counterintuitive. It would make more sense if there is a bias towards accuracy for integer durations since players can relatively easily count to reach the target duration. The data shows the opposite is true. Perhaps counting is less accurate than a more intuitive internal sense of time? If that's the case, this data may help reveal where timing is more or less stable in humans. Could it be that timing in the brain is precise and stable, while motor control deviates greatly because signals need to travel along various pathways for motor control?
Another likely scenario is that the intermediate target durations are much easier to produce accurately because they increase incrementally. Producing 10.2 seconds with 0.1 second accuracy may be extremely difficult, but if the player had successfully produce a 10.0 second duration recently, the memory of that duration may help. An alternate version of the game that presents random target durations instead of sequential durations may help answer some of these questions.

Building a game explicitly around timekeeping meant the interface needed to show the time elapsed, without offering clues that may bias the player. The original design used the volume button as the primary input, so players could play without looking at the screen. This strategy turned out it was against Apple's guideline, so the alternative was to enable the entire screen as a single touch interface.

3.3d Evaluation/Conclusion

Tempra currently has over 3000 active players that enjoy the app and continue to contribute data. The initial analysis will show whether more data needs to be collected or if there are new game scenarios that could be implemented to gather new kinds of data.
Tempra has a very particular incremental trial scheme where each level increase in difficulty by increasing the duration. There are several other schemes that might produce different data. For example, each level could have a random duration, with only the error window decreasing to increase the difficulty of each level.

Quick player surveys (in the form of yes/no questions) would provide important information that could correlate player performance to player psychology. For example, time perception may be more or less accurate while waiting for the bus or jogging.

With enough data, we maybe able to chart how game play increases or decreases an individual's time production accuracy. It's likely that accuracy will increase as more time is spent playing, but if accuracy diminishes when players stop playing, it would be interesting to find out the rate at which it diminishes.

Turning on several sensors on the mobile device may also provide new insights. For example, the microphone could listen to ambient noise conditions, or the accelerometer can determine how heavy or light handed the player is when touching the screen. Collecting data of this kind, could show the relationship between player performance and environmental and physiological variables that haven't been considered before.

3.4 Device 4: Darkball

Darkball is a simple casual game for iOS devices. Darkball was built in collaboration with the Jazayeri Lab in the Brain and Cognitive Sciences department at MIT. The game builds upon an experiment that the Jazayeri Lab has used to study timing in humans and monkeys in a lab context. By reframing the experiment as a casual game, we are collecting new timing data from the global public.

From the Appstore description:
"Tap the screen when you think the ball will appear in the target. The ball will only flash twice. The first flash happens when the ball drops and the second flash happens on the line. You're goal is to tap the screen when you think the ball will appear in the orange target area."

"Cristiano Ronaldo can famously volley a corner kick in total darkness. The magic behind this remarkable feat is hidden in Cristiano's brain which enables him to use advance cues to plan upcoming actions. Darkball challenges your brain to do the same, distilling that scenario into its simplest form - intercept a ball in the dark. All you see is all you need."
"One of the brain's fundamental functions is to use information from the past and present to predict the future. This function is key to how animals, from dragonflies to humans, navigate a dynamic and uncertain world. To make predictions, the brain must have an "internal model" of the system it interacts with. A basic form of this function is at play when we move our body. For example, to reach for a cup, the brain must have a model to predict how the hand will respond to various motor commands. Internal models are also thought to play a crucial role when we mentally predict future states of the environment, for example when we track a ball as it moves behind another object. Here, we have designed a simple task to understand how the nervous system makes such predictions. In this task, subjects have to intercept a ball when it reaches its final position. By changing the speed of the ball, the intervals when it is invisible, and the target position, we will test various hypotheses about the algorithms that are used to integrate information about past and present to make predictions about the future."

Darkball is available for download at bit.ly/darkball

3.4a Background

The game interaction strips away everything that is unnecessary and focuses solely on the user's ability to predict when a ball will appear at a target by inference of momentary flashes of a moving ball. At the core of this interaction is our ability produce predictive models of the world around us. Timing is inherent in everything we do. To understand speech or to pick up a pencil, our brain is constantly predicting when and where things are going to happen.

3.4b Design and Engineering

In order to collect scientific data from users of this app, many considerations were taken into account in the visual and interaction design of the app.

The simple and minimal user interface was necessary to adhere to the demands of data collection, while maintaining the look and interaction of a game. Animation of the elements provide pleasurable feedback to the user without influencing the core timing measurements of the user.

The screen refreshes at 60 frames per second, so a skipped or missed frame can alter the timing of the duration by 16 or more milliseconds. Duration lengths are therefore programmed to account for the screen refresh rate. Take for example a duration of
640 milliseconds. If one flash occurs at 0 seconds and the second flash is intended to flash at 640 milliseconds, because the screen refreshes only 60 times per second, the flash wants to occur at frame 38.4. Since screen freshes are discrete, the flash will actually occur on frame 38 or frame 39 (not in between them). So instead of the flash occurring at 640 ms, it will occur at 633.33ms or 650ms. Extensive testing and great care is taken in Darkball to ensure these measurements are precise by synchronizing to the framerate of the device.

The graph below shows how the framerate of iOS devices are continuously compensating for the refresh speed of the previous frame.

To further exclude any hardware issues that might delay the iOS device's display, a test setup was implemented by the Jazayeri lab to compare the app's internal real time timer and the display's timing accuracy through a photodiode placed on the screen. The maximum deviation found here was 5ms.
Furthermore, although iOS devices have the fastest touch response latency for smart mobile devices, there is 55ms delay on average between the moment of touch and the registration of the touch by the software\textsuperscript{44}. This small, but relatively large, delay is stable enough to compensate within the data calculations.

The visual design of the game is flat and minimal to adhere to the constraints of the data collection process. The elements are designed as an abstract view of a ball dropping in a dark room. Many visual timing cues were eliminated or randomized to remove any timing context to the trials. In other words, any hint that might bias the player's timing over the course of the game were disabled to keep the highly sensitive data as isolated as possible. For example, the time between the end of a trial and the beginning of the next is randomized to be anywhere between .5 - 1.75 seconds so a rhythm can't be established that might produce artifacts in the way a user develops strategies for playing the game.

\textsuperscript{44} Available at:
In order to collect data for research purposes, after the first round, the app asks the player for consent to collect data along with a non-identifying questionnaire.

### 3.4c Contributions

Through the process of building Darkball, insights into latencies in hardware and software were revealed. These sub-second delays are often disregarded as negligible to the overall performance of casual games or tasks, but our experiences from removing 50-20 millisecond latencies during development have affected game scores by an order of magnitude.

This seemingly minute an imperceptible difference in timing may be generalizable to a wide range of human-computer interfaces with significant ramifications to the ways we design and build human computer interfaces.
As a design case study, Darkball has shown how the constraints of scientific research can be integrated into a mobile platform as a casual game for the general public.

3.4d Evaluation/Conclusion

Underneath what seems like a trivial game, is an extremely precise framework for displaying and recording user input on iOS.

We have yet to gather enough data through Darkball to warrant scientific analysis and there is no guarantee that any major insights will come from the data. We remain hopeful and are continuing work to build new experiments using Darkball as a platform.

There may be a slew of scientific experiments that are distributed to the public in the guise of casual games. I hope Darkball provides a strong case for this approach to experimental human subject research.
4. Conclusion

This thesis presents an investigation into the design and engineering of alternative timekeeping devices with a focus on how each device can alter our relationship to time.

How do we keep time? How are we kept by time? Can we alter our relationship to time through alternative timekeeping devices? This work seeks to answer these questions as part of an ongoing personal investigation and exploration in time and timekeeping.

Building upon previous work in constructing alternative timekeeping devices, here attention is paid to how a device might affect a person’s internal sense of time. Could time perception be trained like a muscle? If so, how would a heightened sense of time affect an individual's well being?

The devices presented here were created to address these questions. A strong focus was placed on design as a means to provide a delightful experience and to produce a more impactful effect than traditional lab experiments.

This is part of an ongoing series of attempts to create alternative timekeeping devices. In these attempts, the invisible temporal forces we live by and take for granted will be peeled away.

Over the course of working on this thesis, I've kept a small journal of timepiece ideas to continue to think about the ways we keep time. You can read them at 100timepieces.tumblr.com. Some of these ideas became the seeds of this thesis and may be the seeds of future work.

If this thesis will be of some use to those who are interested in alternative timekeeping and contributes to our understanding and relationship to time, I would consider this thesis a success.

Some future directions of this work include:

Possible spin off version of MA-6 in collaboration with the Eagleman Lab for a sensory substitution project.

Production of Time from Launch in limited quantities as an art product.

Research for Tempra continuing with a new collaboration with Moran Cerf to better understand timing delays in between brain signals, action and awareness.
Research for Darkball, in collaboration with the Jazayeri Lab, continuing in the form of alternative casual games to test other hypotheses on human timing.
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