Thumb-To-Finger Gestural Peripheral Interaction Design For Everyday Smart Home Related Tasks

Jente Insing

Graduation Thesis
Media Technology MSc Programme
Thesis Advisors: Edwin van der Heide, Dr. Roel Vertegaal
Januari 26, 2020

Abstract

In everyday life, we can perform multiple activities simultaneously without consciously paying attention to them. Most interactions with digital interfaces require a person's full focus of attention, even when performing a small task. Since our homes are becoming more digitally controlled with smart lightning, multiroom music systems, smart thermostats or automatic roller blinds, controlling them becomes more cumbersome and requires a person's full focus of attention because they often need to be managed through smartphone applications. In this paper, we explore how freehand gesture-based interfaces can be designed so that interaction with multiple smart home devices can take place in the person's periphery of attention. Peripheral interaction requires only a limited amount of mental resources and requires only minimal attention by making optimal use of a person's capabilities. This means that a person would even be able to perform a more mentally demanding activity at the same time. Most studies focusing on controlling home devices focus on interaction with only one device at a time. Our study explores a novel way of interaction by combining a thumb-to-finger freehand gesture-based interface with vibrotactile feedback to control multiple smart home devices in the periphery of attention.

In this study, we compared the results of our participants performing a high cognitive task while simultaneously performing secondary tasks with our proposed system, and in another condition, a secondary task we know that it can be performed in the periphery. In the high cognitive task, significantly more errors were made while using our proposed system. Also, participants were significantly slower performing a high cognitive tasks while performing a secondary task with our proposed system. Furthermore, we did not find a significant difference comparing only the secondary task durations of both conditions. From our results we cannot

conclude that people can interact with our proposed system in the periphery, but we believe that by more training, improving our prototype and interaction design it could have potential.

1. Introduction

Years ago I saw a talk on the internet by Golden Krishna titled: "The best interface is no interface" where he envisions a screen and interface-less society arguing that screens are an obstacle between the user and his goals and often unnecessary [1]. He argues that we have become obsessed with making a digital interface for everything only to be innovative. An example he shows is the digital car key. A mobile application that lets you open your car, so you do not need to grab your keys. Although this seems to be a good idea, instead of a two-step interaction, grabbing your keys out of your pocket and unlocking the door, the digital variant became a twelve-step process. From picking you phone out of your pocket, unlocking your phone, finding the app to finally having opened the car, making it a cumbersome experience. A disadvantage of screen-based interfaces is that they rely heavily on our sense of sight and therefore require the full focus of attention [36]. This makes it difficult to be performed when doing other activities. In everyday life, physical actions, like grabbing your car key and opening the car door can be done almost completely in the background of our attention. These forms of interaction are also known as peripheral interactions; interactions that can be done subconsciously outside the focus of attention using only a few mental resources. This makes it possible to perform another task in the foreground and thereby perform multiple activities at once. [30]. The increasing number of computer devices in our physical environment, such as *Internet of Things (IoT)* devices or smart home devices makes exploring the area of peripheral interaction increasingly relevant to help people control those devices without becoming visually and cognitively overwhelmed by it due to our limited visual attention and cognitive resources [28]. Because of this, it becomes highly relevant to look at other types of interaction techniques that rely less on our sense of sight and use other bodily capabilities often missing in today's interfaces. For example, *Tangible User Interfaces* (TUI) which rely on our kinesthetic senses, or gestural interfaces relying on our spatial motor memory and proprioception. Such approaches could make it easier to perform these tasks during other activities because they can be performed with minimal conscious control [23] and supports eyes free interaction [5].

We will explore the use of freehand gestural interfaces as interaction method for peripheral interaction by creating and evaluating a new interface through a prototype. This leads to our general research question: *Does a thumb-to-finger gestural interface for single-handed use in combination with vibrotactile feedback have potential for performance in the periphery for smart home control related tasks?*

The main contribution of this paper in the field of peripheral interaction is presenting and evaluating our hand based gestural interface with subtle finger interaction to gain new insights in the design for peripheral interfaces. Furthermore, we contribute to the field by studying peripheral interaction in the 'smart home' context which is a relatively new area.

To answer our general research question we first study the literature on the following aspects:

1. Current knowledge on peripheral interaction and attention theory
2. Bodily abilities that can be used to achieve peripheral interaction
3. Exploring interesting interaction styles that could be suitable for peripheral interaction

Based on the literature we will define the requirements for the proposed system. Based on these requirements we will create a prototype and perform a research-through-design method to answer our research question. We chose this method because we are interested in applying the theory about peripheral interaction in an interactive system and to evaluate the theory in practice so that it could be interacted with in the periphery of our attention. As a tool to study our research question we create a prototype: a freehand gesture-based system to interact with IoT devices such as lights, roller blinds and a music player in a living room environment.

2. Related Work on peripheral interaction

We will begin by describing past and current research about peripheral interaction and attention theory to understand what peripheral interaction is and how we can implement the theory for our proposed system.

2.1 Peripheral interaction

As earlier mentioned, the Graphical User Interface focuses highly on our sense of sight, which usually requires our full attention even if the task is relatively easy [4]. Because of this, a lot of our cognitive resources are being used, distracting us from performing other activities simultaneously. In the physical world, a lot of our interactions are performed in parallel. We both perform tasks in the periphery or background of our attention while performing another task in the center of our attention. We can read a book and at the same time drink a cup of coffee, or we can talk with someone while simultaneously preparing dinner. Physical interactions like drinking, preparing a meal or turning on the lights in your home requires minimal attention and can be performed outside our focus of attention. These types of interactions are called 'peripheral interactions' and can easily be performed simultaneously with another higher cognitive task [5].

The dominance of the screen and the use of only our visual sensory system does not allow for peripheral interaction [36]. Only one modality is used while we humans can easily handle multiple modalities at the same time. Because of this, Mark Weiser and John Seely Brown introduced the concept "Calm technology" in 1995 which they describe as 'technology that engages both the center and periphery of our attention and in fact moves back and forth between the two' [4]. They envisioned how we could interact with digital technologies in the periphery so that the interactions can disappear in the background of our attention and can move quickly from the background to the center of attention and the other way around when needed. To qualify an interaction as peripheral, the interaction must not distract the user from another mental demanding activity or at least reduce the interruption to the interaction to a minimum. Only one activity can be in the center of attention at a time, so peripheral interactions need to shift quickly between center and periphery when activities are done simultaneously [6]. To design for peripheral interaction, we first need to understand how humans use and divide their attention. In the next section, we will focus on this area of research.

2.2 Divided attention and interaction

Peripheral interaction highly relies on divided attention theory. This theory describes how people can perform multiple tasks at the same time. Our brain only has a fixed amount of mental resources which could be divided over different activities. Such activities are bodily activities, (e.g., walking) sensorial activities, (e.g., listening to music) cognitive activities (e.g., solving an equation) or a combination of those [28]. This mental limitation and the type of activity a person performs, depends on the number of activities one could perform simultaneously. A lot of activities in our everyday life can be automated with training and exercise. Those kinds of activities can decrease the number of mental resources needed for a task when a process has become automated [29].

An Automatic process only uses a few mental resources because, with training and experience, we do not have to think about them anymore [29]. When you learn to drive a car for the first time, you have to use a lot of mental resources. You have to learn how to gas, brake, and steer, how to change gears, while also focusing on everything happening on the road. While this is difficult in the beginning, with enough experience, this activity will become an automatic process and can be performed unconsciously. This allows us to allocate the freed mental resources to perform other, more mentally demanding activities, like having a conversation [30]. Besides automatic processes, there are controlled processes [29]. Controlled processes like, for example, reading or solving equations, cannot be automated. They require a lot of mental resources and need to be done consciously with full focus. They require us to think, evaluate, and make decisions [29]. This type of process makes it almost impossible to perform other controlled tasks at the same time, without switching between the task consciously. Bakker and Niemantsverdriet [31] described this theory in combination with interaction design and developed a concept called the Interaction-Attention Continuum. They divide attention theory in combination with interaction design in three categories: Focused interactions, peripheral interactions, and implicit interaction (figure 1).

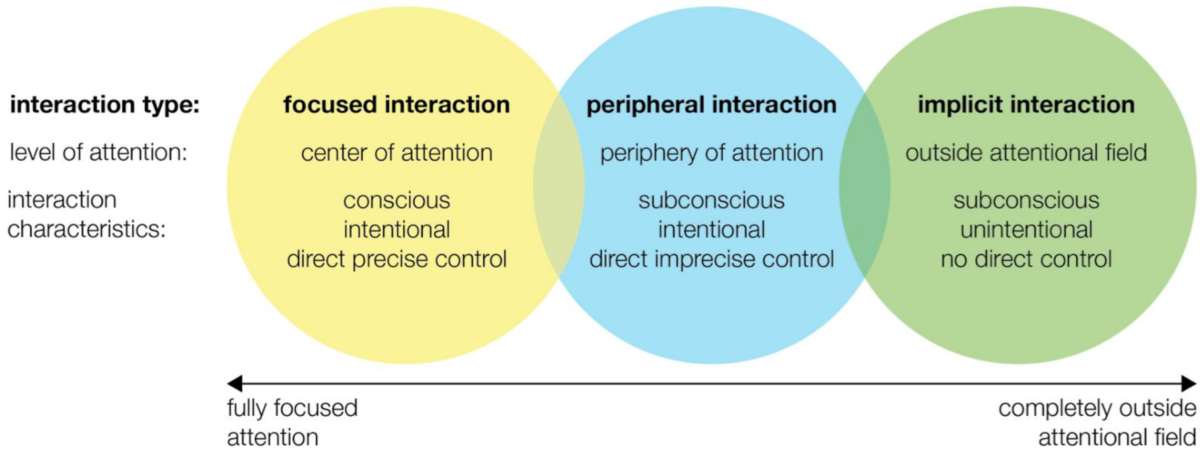


Figure 1: Three types of interaction by S. Bakker & K. Niemantsverdriet [31]

Focused interactions are interactions that use the most mental resources and take place at the center of attention, are performed consciously, with intention and we have a high level of motor control during the interaction. This is the most common type of interaction with computers and touchscreen devices, but also very common in everyday life. Think of messaging someone, browsing a website, but also making coffee, using the microwave, or having a conversation with someone. To perform interactions like these, the user needs to be focused to get the information from the system needed to be able to interact with them. Because of this, it is tough to perform other activities simultaneously.

At the other end of the spectrum we find implicit interactions [31]. These are interactions that we have no control over and are performed unconsciously. Most interactions with such systems are systems that track the environment via sensors. We normally interact with those systems while we do not aim to interact with them consciously. However, the system understands those interactions as input and acts on that. Think of walking towards a door which opens automatically or the lights turning on when walking in a room. This type of interaction does not use any mental resources unless the system does not work correctly.

In between those interaction styles we find peripheral interactions [31]. These interactions are done subconsciously and are often performed automatically, which means that only a few mental resources are needed. This type of interaction does not demand full focus of attention (e.g., walking in a known room and switching the light on by pushing the light switch). When performing such actions, we do have a low level of motor control, meaning that is difficult to perform very precise motor control during an interaction. Most peripheral interactions have to be trained and while learning use a lot of mental resources. With experience, the amount of mental resources will reduce and the interaction can become automated and eventually become peripheral. Typing, for example, will take a lot of mental effort when learning, but with years of experience we do not have to think about where the keys are, but instead we can use those mental resources about our writing.

The three types of interaction described above can be performed simultaneously. When an activity takes place in the center of attention, we can perform an implicit or peripheral activity at the same time when the focused interaction does not consume too many mental resources and does not use the same sensory modalities. When different activities use the same sensory modalities, they can interfere with each other, making it harder to perform these activities simultaneously [29]. For example, we cannot read a book and watch television at the same time or listen to music and have a conversation without losing focus of the other activity. Two visual activities or two auditory activities are hard to be done at the same time, but an auditory and bodily activity or an auditory and visually activity, for example, can [29].

An activity can thus be performed in the periphery when simultaneously performing a mentally demanding activity. It is important that the high cognitive task does not use all mental resources and that both activities do not use the same sensory resources [12]. When designing for peripheral interaction, it is important that the activity is simple enough to become an automated process and that the sensory modalities needed to interact with the system do not conflict with the sensory modalities needed for the mentally demanding task. Physical actions are easy to automate and therefore have great potential as input for peripheral interactions [5]. Because our actions in peripheral interaction are not very precise, it is important not to give the users very sensitive input options that only can be used with fine motor skills.

2.3 Examples of peripheral interaction

Several studies have explored the field of peripheral interaction, exploring different interaction methods for digital interfaces. A lot of studies focus on tangible user interfaces (TUI) to control a digital environment.

Hausen & Boring [33] studied the effectiveness of tangibility in peripheral interaction using a device called StaTube (see figure 2a). With this device people who use Skype in a working environment could easily change their own Skype status in the periphery by rotating the top ring of the device and see the statuses of other colleagues via the other rings. During their research they found that the tangibility allowed for peripheral interaction. The participants did not have to lose focus of their primary activity to change their Skype status. Also the participants were more eager to change their status, making these more reliable for the other colleagues.

Figure 2: Statube (a) , Whack gestures (b), Polytags ©

Another example of peripheral interaction is “whack gestures” (figure 2 b.). This is a device that is worn on the belt designed for use without fine motor skills and supports eyes free interaction [15]. Using this system, the user can respond to a notification on its mobile phone/PDA by striking or whacking the device while the phone is in the pocket. Because the user does not have to get its phone out of its pocket, the interaction is less intrusive and does distracts the user less from another activity.

Figure 2c shows Polytags by Olivera et al. [24] which is a tangible device in the form of a multi-faced dice. Every side has a marker to control devices in a smart home. Participants could turn on the television or the heater by turning the dice. in a lab study participants had to use the device while simultaneously count vowels in a text. This research showed that participants made significantly less errors in the vowel counting task while using the dice compared with a traditional GUI. This implies there was less distraction by making the interaction peripheral using tangibility.

Besides tangible interfaces, multiple gestural interfaces were explored for interaction in the periphery. The 3Dee flexible chair [34] is an example which uses a gestural interface that turns a flexible chair into an input device for desktop computers in a work environment and create a hands-free always available interaction to interact with a music player by tilting or rotating the chair with your body when seated.

Hausen et al. [25] compared three input methods (Tangible, touch and freehand gesture input) with a mouse and media keys for peripheral interaction. In an eight-week in-situ study, participants had to control a music player on a desktop computer. They found that all input devices reduce the cognitive load in comparison with mouse input and could be used in the periphery. While the tangible input method scored best for peripheral interaction, she states that the other input methods can be successfully used in the periphery when tangible interaction is not an option.

3.0 Interactions styles

Physical interactions are a good way to facilitate peripheral interaction with technology. Because we are familiar with them, they can become automated, and by using our sense of touch, it will not conflict with the visual modality. In this section we will explore which interaction styles could be suitable for peripheral interaction to inform our design and prototype.

3.1 Tangible User interfaces

Research into tangible interfaces started with Fitzmaurice, Ishii & Buxton (1995) [7] Who introduced the concept of Graspable User Interfaces, the precursor of the Tangible User interface. In their first study to graspable interfaces, they created wooden blocks called bricks, which acted as an input device to manipulate and control objects on a screen. By attaching one of the bricks to a digital object on the screen and moving the other brick over the screen, the user could rotate, stretch or move virtual objects in a drawing application by physically manipulating them. This created a direct two-handed tangible experience which is similar to our everyday interactions with objects. Based on the work of Fitzmaurice and its colleagues, Hiroshi Ishii introduced the term Tangible User Interfaces with the Tangible Media Group at the MIT Media Lab (1997) [8]. AmbientROOM (1998), a study of Hiroshi Ishii's Tangible Media Group, explored peripheral information retrieval by using ambient displays [9]. The AmbientROOM in this study functioned as an interface displaying digital information by making use of peripheral cues like sound, light, haptics, and movement to alert the user in the periphery of their attention of changes in data. For example, the movement of a hamster in a cage would be projected as water ripples on the ceiling, showing light patterns on the wall to display activity of people in the atrium adjacent of the room or changing the light in the room based on the time of the day so the user knows based on the light fall what time it is. Although this research does not focus on interaction but on perceiving information in the periphery, this shows that interaction with our devices should give appropriate feedback to not distract the user from its primary task [10].

Fitzmaurice showed with its research on Tangible User Interfaces that putting tangibility into our digital interactions can help to support two-handed interaction, parallelization of tasks and because they make use of our haptic senses, it can help reduce the mental resources needed and an increase in performance [11].

3.2 Micro-interactions

Oulasvirta et al. [37] showed that in a mobile context, users could only interact with their mobile phone for 4 to 6 seconds before they had to refocus on their environment. If the interaction will take longer, the user will be constantly interrupted making the task cognitively difficult. Based on this research Ashbrook [12] came up with the term micro interactions. Ashbrook states that

Microinteractions are interactions with a device that needs to take less than four seconds from accessing a device to completion of the task. This interaction needs to be performed with almost no mental effort [13] and if possible eyes-free [14] so that the user can quickly shift back to its primary activity.

Microinteractions can minimize the time of interruption so the user can quickly shift back to its main task. Such interactions could be switching songs, turning on the light, changing the temperature on your thermostat, etc. Wearables can allow the interaction to be always accessible for the user which means it can minimize the access time in comparison with a mobile phone. This makes it easier to perform a simple task in parallel with a primary task [13]. We will describe some studies that focused on micro-interactions enabling eyes-free interaction. Although these studies do not focus on peripheral interaction these studies can be used as inspiration.

Harrison et al. (2010) created an interactive system called "skinput" which transforms the arm and hand into a touch-sensitive surface [16]. With a bracelet, they measured the acoustics of the waves propagating the body when the skin is touched to distinguish and classify the area the finger touches the arm.

PalmRC [17], a project of Dezfuli et al. (2012) created a similar prototype but using a Kinect camera to classify body parts allowing bodily touch interactions. They made a prototype where the user could touch on their hand palm with their index finger of their other hand to control a television.

In both studies they make strong use of our sense of proprioception (the sense of knowing where your body parts are) so that although the interface is touch, which is usually not a suitable interaction method for eyes-free interaction because of the limited amount of feedback the user receives, this approach does allow eyes-free interaction and because hands are always available it minimizes access time.

Digits (2012) makes use of an infrared camera in combination with a laser worn on the wrist that tracks the movements and gestures of the user's hand [18]. Different freehand gestures like pinching, making a fist, 'ok' or call sign were classified so that the user could interact with the interface. In one of their demo applications, they demonstrated how to interact with a radio, like changing the volume by moving a virtual slider or changing the radio channel by rotating a virtual rotating knob making fast and easily accessible interaction possible. However, they do not make use of other types of feedback, such as vibrotactile feedback, than the auditory feedback from the radio. This makes it in other contexts, when the feedback of the system is more slow, like changing the temperature of the thermostat, hard to create eyes free interaction. Interesting about an interface like this is that when the user has experience with a physical radio 'transfer learning' could be applied. The spatial memory one has learned by interacting with a physical radio could easily be transferred to other contexts [19] like a digital or invisible interface.

DigitSpace [20] explored if the different parts on your fingers could be transformed into invisible buttons by using magnetic tracking. The virtual buttons can be manipulated by using the thumb as a stylus. To interact, you could either touch, slide, or rotate the thumb to interact with the device. In their study, they found that participants could distinguish about 16 buttons on their fingers on one hand.

3.3 Key findings

Below is a short summary of the concepts and findings regarding peripheral interaction base on related work. Based on these findings we will develop an interaction design and prototype to research peripheral interaction design in a smart home context using a virtual interface.

1. Physical interactions can be automatized by training and experience and form therefore a good interaction type for peripheral interaction [5].
2. When interactions become a routine the interaction will require almost no mental resources [31]
3. Eyes free interaction minimizes distraction time and mental demand [14].
4. The use of micro-interactions minimizes the time that the focus goes away from the primary task. This means that the system needs to be easily accessible and executable in 4 seconds allowing the user to instantly go back to its primary task. Eyes free interaction, leaving the hands empty and minimizing modes and navigation could help with that. [13]
5. Interactions in the periphery of attention are not precise. [31]
6. Imprecise interactions are easier to learn, to memorize and to perform because it makes no use of fine motor skills [34].
7. Making use of bodily skills such as proprioception and spatial memory in your interaction design can support eyes free interaction [5] and using less mental resources [23].
8. The hands are most used for peripheral interaction. Haptic perception is an important part of our peripheral interaction in the physical world [12].
9. Tangibility helps to support the parallelization of tasks [11].

Based on our findings, we will propose and design a peripheral controller that makes use of freehand gestural interaction techniques with thumb-to-finger interactions to investigate if such an interface has the potential to be performed in the periphery. Although hand-based gestural interface designs are already studied [5, 15, 25] in the field of peripheral interaction, we did not find studies exploring freehand gestural interaction with subtle finger interactions. Furthermore, we did not find studies combining gestural interactions with additional tactile feedback investigating peripheral interaction.

Therefore, we will investigate whether a hand based gestural interface with subtle finger interactions and combined with tactile feedback can be used for peripheral interaction.

4.0 Peripheral interaction in a smart home context

Now we have an understanding of peripheral interaction and suitable interaction styles we can use for our proposed system, we will discuss the context of use in this section. Based on this context, functional requirements will be specified which our interaction design will be based on.

4.1 The smart home

The context in which we decided to focus our study on is the (smart) home environment. Our home is typically an environment which is completely physical, allowing us to interact easily within the periphery of our attention. If you want to turn on your lights, you click on the light switch in the room or if you want to close your curtains you just pull them. Our homes will become more digital. Smart lights like Philips Hue[1] or the smart Ikea roller blinds[2] allow you to control your lighting and curtains via your smartphone. Thermostats are becoming smart and learns your behavior, and more devices like your fridge, oven, doorbell, or door locks will be connected to the internet. Nowadays this means that when you want to interact with a device, you have to pick up your phone, find the right applications, and click on a virtual button to turn it off. We think this is not an ideal type of interaction because it cannot be performed in the periphery. Another way of interacting with your smart home can be done using voice-based input via assistants like Siri, Google Assistant or Amazon Alexa. Interactions with those systems are controlled [29] which demands more mental resources and cannot be automated. Besides this, another reason to choose the smart home context is that, as earlier mentioned, controlling for example your lights are types of interaction that are a routine activity and these interactions are very suitable for peripheral interaction.

4.1 Designing the peripheral smart home controller

A lot of related work focuses on peripheral interaction for only one particular goal. This has advantages when interacting because there are only a couple of actions possible. However, we think this is not the right approach, because it is not practical to carry multiple devices around. Instead, we believe that the 'one device to rule them all' approach will be more scalable to accomplish various tasks with different devices.

Therefore we have to focus on the question how we can map the interactions in such a way that the interaction is intuitive enough to operate it in the periphery of our intention and

[1] https://www2.meethue.com/
[2] https://www.ikea.com/nl/nl/customer-service/product-support/blinds/

scalable enough to control multiple and different types of actions. Another challenge is that our home devices are becoming more advanced. Smart lighting systems have more advanced functionality than our old fashioned light bulbs, such as changing color, color temperature, or brightness. Because of that, a simple on/off switch is not sufficient anymore.

4.2 Interaction styles

In section 3 we found that multiple interaction styles are suitable for peripheral interaction with the hands. The best known techniques are graspable/tangible interaction, touch interaction, or freehand gestural interaction.

In this study, we will explore thumb-to-finger gestural interaction because it heavily relies on our bodily capabilities like spatial memory and proprioception, [32] which can support eyes-free interaction and has the potential that it could easily be learned because the interactions are more natural than traditional interaction methods.

It is important, when designing for peripheral interaction, that the set of gestures is small to reduce the need to think about the correct gesture [35]. Other concerns we have to take into account using this interaction method are that the interface does not reveal its functions and gestures in any visual way which means that the user has to recall the systems interactions from memory. This could make learning how to use the interface harder compared with a visual interface which relies on recognition. Besides this, gestural interfaces lack inherent feedback, the information that is naturally returned from the system (e.g. the feeling of a click when pushing a button), making it difficult to know whether an gesture is successfully recognized by the system when the action does not give functional feedback, like interacting with a roller blinds [10]. When you interact with roller blinds, it takes a while before it is in the right position, depending on the power of the motor controlling the roller blinds. Besides those concerns, we think that freehand gestural interaction could have a great potential for interaction in the periphery.

4.3 Hardware

We created an interactive glove using a gyroscope and an accelerometer (6-dof) on top of the hand to sense the hand's angular orientation and the speed of rotation. On all the fingertips of the glove, we added conductive sensors to detect which finger touches the thumb. Furthermore we added a small vibrating motor placed on the thumb for haptic feedback. All this is connected to a Teensy 3.2, which is placed on the wrist and connected to a computer with a cable (see figure A).

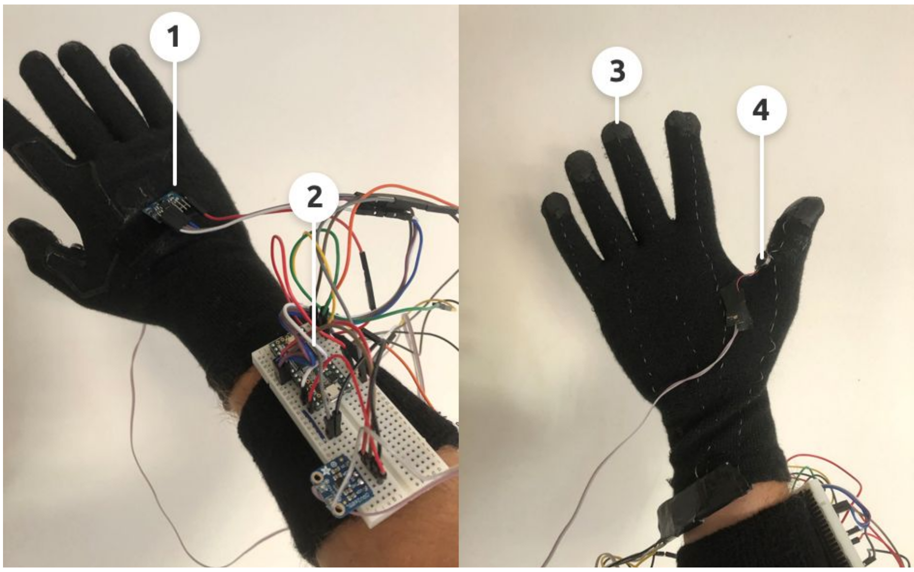


Figure 3: Prototype: (1) 6-DOF Accelerometer/gyroscope (2) Teensy 3.2 (3) conductive sensors (4) Vibration motor

4.4 Interaction design

Because we design for peripheral interaction, we cannot make use of visual clues to help the user remember where which functionalities can be found and how to interact with them. All actions the user performs needs to be easy to remember and easy to use, so that as little as possible mental resources and attention will go to the interaction with the glove. For this study, we choose to interact with three home appliances most people can relate to and use on a daily basis in their own home. We chose to use a lamp, a music player and roller blinds. Each device is assigned to a specific finger which can be activated by touching and holding the thumb to the preferred finger the device is mapped on. Table A. shows the input mapping we will use to interact with these appliances.

Device	**Finger**	**Functionality**	**Interaction**	**Functional feedback**	**Inherent feedback**
Lamp	Index	Brightness	Tap and rotate	Visual	Haptic
	Index	Color	Double tap and rotate	Visual	Haptic
Roller blinds	Pink	Moving up and down	tap and rotate	visual	Haptic
Music player	Middle	Play/pause	pushing hand down	Auditory	Haptic
	Middle	Next/previous track	Tap and rotate	Auditory	Haptic
	Ring	Volume	Tap and rotate	Auditory	Haptic

Table A. Input mapping for interacting with different devices

By touching one of the fingers against the thumb and holding them against each other, the system will start listening to commands. The current orientation of the hand will be used as the starting position for the interaction with the system. By rotating the hand to the left or to the right, the value can be adjusted. When a user taps and holds the index finger against the thumb the brightness of the lamp can be increased or decreased in steps of 10%. While rotating, the user will get haptic feedback for value change.

Because a lot of devices have multiple functionalities, e.g. smart lights can have different colors and brightness levels, the user can double tap and hold to select another functionality. Ending the interaction with the system can be done by releasing the finger of the thumb.

5.0 Usability Evaluation

When designing for peripheral interaction it is important that the system performs flawlessly. Therefore, we will we will perform a usability test to identify usability issues, acceptance of the interaction method in the smart home context, to find bugs and to collect qualitative feedback in order to improve our proposed system before we will conduct the final experiment.

Three participants (1 female, age 26 - 31, all right handed) took part in this usability test. All participants had some experience with gestural interaction through VR game controllers and some experience with smart home devices, such as smart lights or Google home assistant.

5.1 Apparatus and setup

The experiment was conducted in a living room environment. A laptop in combination with the prototype was used to conduct the test. The participants sat in a chair with their dominant hand (wearing the glove) above the table. in front of the participant on the table a laptop provided visual feedback to the participant in the form of raw Arduino output.

5.2 Procedure

First, the participant was explained what the purpose was of this study and how the prototype worked. After that the participant got some time to get familiar with the system. During the experiment, the participants performed twenty different simple tasks with the prototype to control virtual home appliances like lights, a music player, and a roller blind. By (double) tapping and holding the thumb on one of the fingers, the participant was able to select a function. By rotating the hand to the left or to the right the participant could adjust settings like brightness, volume, the color of the lights, etc. inherent feedback was provided by giving haptic clues during the interaction and in the first part of the experiment functional feedback was provided by showing text on the screen. In the second part of the experiment, the participant had to perform ten tasks, but only haptic feedback was given to the user to test whether the prototype gave enough feedback to interact with without having to look. At the end of the experiment, user feedback was collected through a questionnaire and an interview.

5.3 Results

Most functions used the same gestures. Tap (or double tap) and hold one of your finger to the thumb to select a device and functionality and rotate the hand to adjust a setting. Only the Play/pause music interaction was different. Which is, pushing the hand down as if you push on an invisible button. During this usability test we found some bugs. Double-tap did not work correctly, making it difficult to change the color or volume of the music. Also, it was notable that the double-tap functionality was more challenging to recall than the single tap functionality. All participants learned the different functionalities and gestures within ten minutes. All participants noted that changing color was difficult because it was hard to recall the order the colors are sorted on. This problem did not occur with other functionality, because of the haptic feedback given by the glove and the logical ordering. When for example the instruction was to adjust the brightness with 30% they knew without looking that they had to rotate their hand until they felt the third vibration. This was not possible with colors. To play or pause the music, the participant had to push its hand down till a certain degree as it was an invisible button they had to push in. This was confusing because this was the only gesture that was different than the others and not working well enough. All participants noted that the sensitivity of the rotating gesture was not sensitive enough. Because of that, they had to rotate their hand in a way that was not pleasant. Furthermore, all participants liked to use the system and could imagine using this type of interaction to adjust a smart home device quickly. When removing the visual feedback on the screen, more mistakes were made during the tasks, but these mistakes had mostly a relation to changing the color, which was like earlier said difficult, especially without functional feedback, and the double-tap bug. Remembering which finger corresponds to which device and remembering which gesture corresponds to which function was not a problem.

5.4 Changes after first evaluation

Based on the results of this usability test, we improved the double tap, we changed the sensitivity of the rotating gesture to make it easier to adjust the value without rotating the hand too much. Furthermore, we changed the play/pause gesture to a double tap instead of the push gesture and moved the volume to the ring finger, because there were too many different interactions on the middle finger.

6.0 Final experiment

This study explores if our proposed gestural interface for smart home control related tasks have potential for performance in the periphery. To answer this question, we conducted a user study to evaluate if people can interact with our interactive glove in the periphery. We performed an experiment in which participants interacted with the glove while simultaneously working on an exercise that requires many mental resources and focused attention. If a task that requires many mental resources is performed in the focus of attention and a secondary task can be done simultaneously, we can conclude that the secondary task is performed in the periphery [12]. This section describes the given tasks, study environment, the participants, and the experimental procedure used as part of our method. Based on our related research on peripheral interaction and freehand gestural interaction, we formulated a couple of hypotheses:

Hypothesis 1: We hypothesize that people can interact successfully with our proposed system when they simultaneously perform a cognitively demanding task.

Hypothesis 2: We expect the participants performance on the high cognitive task will be similar while using our proposed system compared with another secondary task that has been proven to happen in the periphery, like drinking from a bottle of water

6.1 Experiment design

Most research in the field of peripheral interaction focuses on long term in-situ evaluations. This has the benefit that the participant gets enough time to get used to it and to integrate it into the participants daily life and thereby can be performed in the periphery of attention. To validate our hypotheses and answer our research question, we conducted a dual-task lab study. Besides long term in-situ studies to learn about the long term usage of a system during daily tasks [23] lab studies are a commonly used research method to study peripheral interaction [24, 5, 25, 26] and have the benefit that it takes less time, usability issues can be found early in the design process and before deploying the prototype in a real-life situation, performance can be measured and participants behavior can be observed more easily [23]. A disadvantage of conducting a lab study is that the learning time is much shorter. Instead of using a prototype for days or weeks, a participant only has minutes to learn how the system works. The interactions cannot become an automated process in such a short time, therefore, it requires more mental resources and more focus [5]. Although the interaction cannot become peripheral in such a short time, the quantitative results like performance and error-rate can give us an indication of the level of disruption and usability issues, before applying it in the field [23].

For this experiment, we chose a within-subjects design where the same participant will test two conditions. During the experiment, the participant performs a task that requires a high level of cognitive demand (HCD task) simultaneously with a secondary task. The secondary task changes per condition. The HCD task should be in the focus of attention, so the secondary task needs to happen in the periphery [23]. Many lab studies on peripheral interaction include hand interactions in the HCD task. Since using the prototype requires participants to use their hands in the secondary task, the HCD task should not involve any interaction with the hands. This is because it is difficult to perform multiple motor tasks at the same time [27]. Therefore, we looked for a method that includes other input modalities in the HCD task. We chose to use the method of Olivera et al. [24] for the HCD task. In their experiment the participants had to count how many times a specific vowel appears in a text which is a task that requires the participants full visual and focused attention.

High cognitive demanding (HCD) task design - We adapted the vowel counting concept of Olivera et al. to the needs of the HCD task in our experiment. The participant will be asked to count how many vowels appeared in the text and call out loud his vowel answer every time the participant sees one. During this HCD task, we measure the speed of completing a text and the difference between the actual amount of vowels and the participant's vowel answer (error)

Secondary task design - The secondary tasks have two conditions. In one, it consists of interacting with the glove. In the other condition, we replace the glove by a task of which it is already known it can be performed in the periphery. We will call those conditions the Glove Task (GT) and the Peripheral Task (PT). During the GT, the participant is interrupted from the HCD task, as he is requested to perform actions like "turn on the light", "skip a song", "raise the brightness with two steps", "close the blinds" using the prototype. In the PT, the participant will be interrupted to grab a bottle, drink from it, put the bottle back, and ungrab it. Of this task, it is known that it can happen in the periphery [5]. Because we use a within-subject design, each participant is exposed to both conditions. To minimize the learning effect, we changed the order in which the conditions will be performed in each test.

6.2 participants

For this experiment we recruited 14 participants (5 male, age 23 - 34) with different educational backgrounds and experience with smart home devices or gesture-based interfaces.

6.3 Setup

The participants are seated on a chair at a table to simulate a normal in-house situation wearing the interactive glove (see figure 4) . On a screen in front of the participant the HCD task will be shown (see figure 5A). Besides the screen, in the periphery of the participants vision another screen will show the functional feedback of the smart home appliances such as a light and roller blind (see figure 5B).

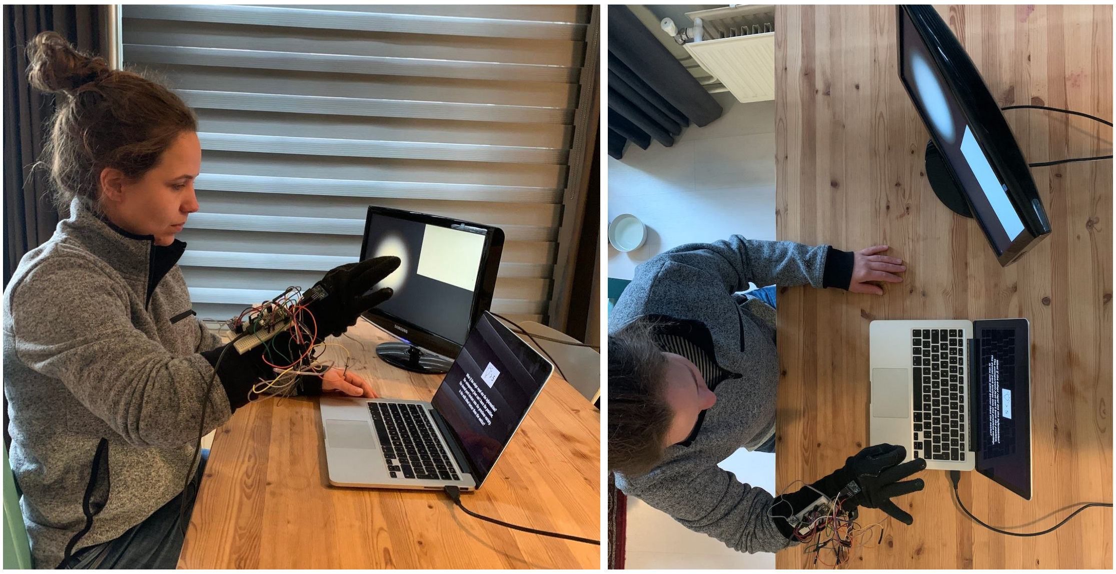
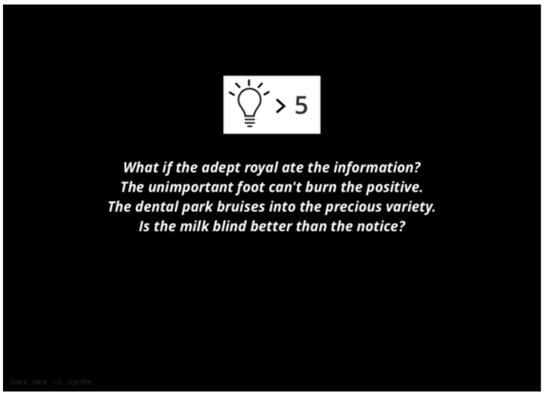


Figure 4: Experiment setup



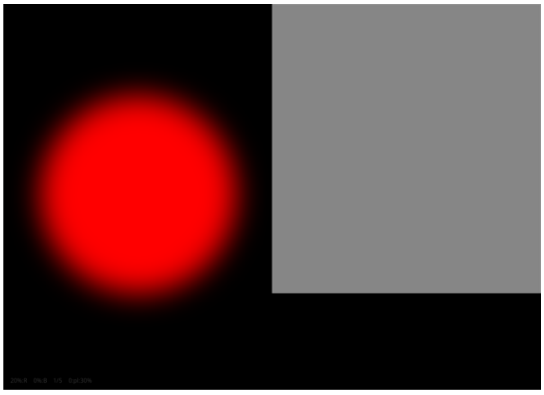


Figure 5A: High cognitive task *Figure 5B: light (left) and roller blind (right)*

6.4 Procedure

The experiment consists of three phases: the introduction phase, the training phase, and the experimental phase. Each participant goes through the following procedure: The introduction phase starts by asking the participant to sign a letter of consent and to fill in a demographic survey, including age, gender, experience with smart home devices, and experience with gesture-based devices. After that, the participant is asked to wear the glove on their right hand. Following the introduction, we will start the training phase. Here the different functionalities of the glove are explained. The participant gets some time to practice on both the HCD task, the PT and GT tasks and is able to ask questions. This takes approximately ten/fifteen minutes until the participant is confident enough to use the system.

After the training phase, the experiment will begin. The HCD task exists of fifteen small texts (each around 20 - 30 words) and will be shown to the participant one at a time. The individual texts will be presented in random order to minimize a learning effect. During the HCD task, a notification appears on the screen in the form of an icon which tells the participant what its secondary task will be. We chose an icon for this, because that does not interfere with the vowel counting task. After all secondary conditions were tested, the participant has to fill in a questionnaire in which the participant rates their experience with the prototype in areas like learnability, ease of use, and mental workload.

6.5 Measurements

To validate our hypotheses, we measured how the participants performed during the GT and PT tasks and compared them with each other. An important aspect of peripheral interaction is that two tasks can be successfully performed in parallel (hypothesis 1). To measure this we will analyze the performance of the participant in the GT condition when performing the HCD task and measure the time to complete the task and the difference between the actual amount of vowels and the participant's vowel answer (error). To measure the performance of the GT task, we will measure the time it takes to complete the secondary task and the number of adjustment errors of the GT task.

Furthermore, since we know that physical tasks like drinking from a bottle of water can be done in the periphery, we will measure what the impact is of this task on the HCD task and compare this with the performance of the HCD task during the GT task (hypothesis 2). This will include, time to complete the HCD tasks and the error rate.

Measurements	**Mean duration (sec)**
Vowel count error rate	The ratio between the errors and the actual number of vowels in the text
Task duration	The mean time it took to complete the primary task and the secondary task
Secondary task duration	The mean time it took to complete the secondary tasks
Secondary task error	The amount of errors made when interacting with the glove in the GT condition.

Table B: Summary of the measurements

7.0 Results

7.1 Quantitative results

Vowel counting error rate: To measure the success in the primary task (vowel counting) we calculated the error rate (Ratio between error and the actual number of vowels in the text). The mean error in the GT condition was 2.50% (SD = 1.33) in the PT condition 1.685% (SD = 1.28). A Paired Sample T-test showed that the in the Peripheral condition (PT) the participants had significantly smaller vowel count errors (P = 0.01813) in comparison with the Devices condition.

Subject	N	Mean error %	SD
Glove condition (GT)	14	2.50	1.33
Peripheral condition (PT)	14	1.69	1.28

Table C: Error rate

Mean task duration: The mean time in the GT condition was 46.38 seconds (SD = 8.75) per task (HCD + secondary task) while in the PT condition the mean time was 40.96 seconds (SD = 10.25). A paired sample t-test showed that participants mean task duration was significantly faster in the PT condition (P = 0.007).

Condition	N	Mean duration (sec)	SD
Glove condition (GT)	14	46.38	8.75
Peripheral condition (PT)	14	40.96	10.25

Table D: Mean duration of the primary + secondary task

Secondary task error: To get an indication of how good the participants performed during the secondary tasks in the devices condition we measured the amount of errors they made (figure 6). We measured if the participant successfully accomplished the task, but accidentally adjusted other functions (Correct, but changed other settings) or did not successfully accomplished the task completely (Incorrect). For example, when a task is given to adjust the brightness with 5 steps, but the participant adjusted the brightness with less or more than 5 steps.

For peripheral interaction it is important that the participant does not make errors, because the task will then move to the center of their attention. We saw that some participants lost count in the vowel task when such errors occurred, which indicates that because of this error the interaction moved to the center of attention.

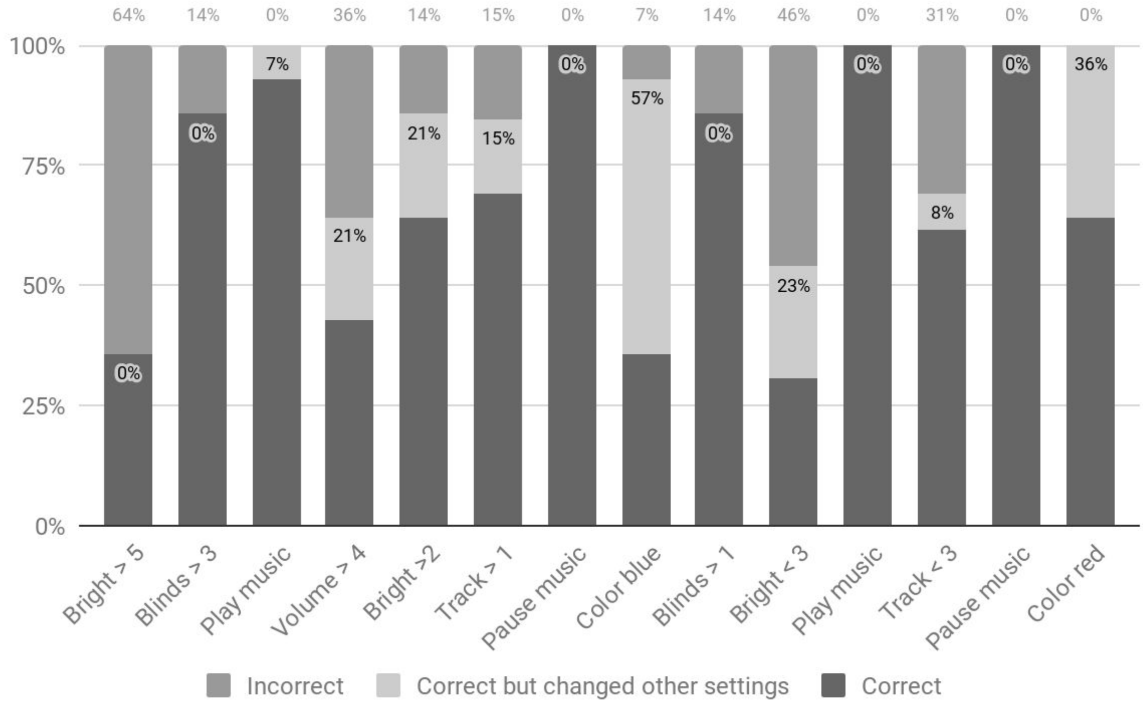


Figure 6: Error rate diagram of the secondary task in Devices Condition of all participants

Most errors were made when adjusting the brightness, but these were small errors. Most participants selected the right device and function, but adjusted the brightness with a step more or a step less. More important errors to focus on are the 'correct, but changed other settings' errors, because here they adjusted settings of other devices or functions before adjusting the right function.

When we take a look at that data we see that most of these mistakes happens when changing color. Most of the time they adjusted the brightness accidentally, which can be done by one tap and rotating the index finger, while they wanted to change the color, which is selected by tapping two times with the index finger. Furthermore, no errors were made when the participants had to pause and play music. This can be explained because there is no other similar interaction (double tap index finger) and the interaction is relatively easy.

Duration of the secondary task: The mean time to perform an individual secondary task in the GT condition was 4.91 seconds (SD = 1,0476) and in the PT condition 3.49 seconds (SD = 0,9246). Using a Paired sample T-test we found that the duration during the PT condition was significantly faster (P = 0,0008). Looking at the different secondary tasks in the GT condition we found large differences in duration between the individual tasks This is mostly because of user errors, small bugs in the system and differences in interactions (see figure 7).

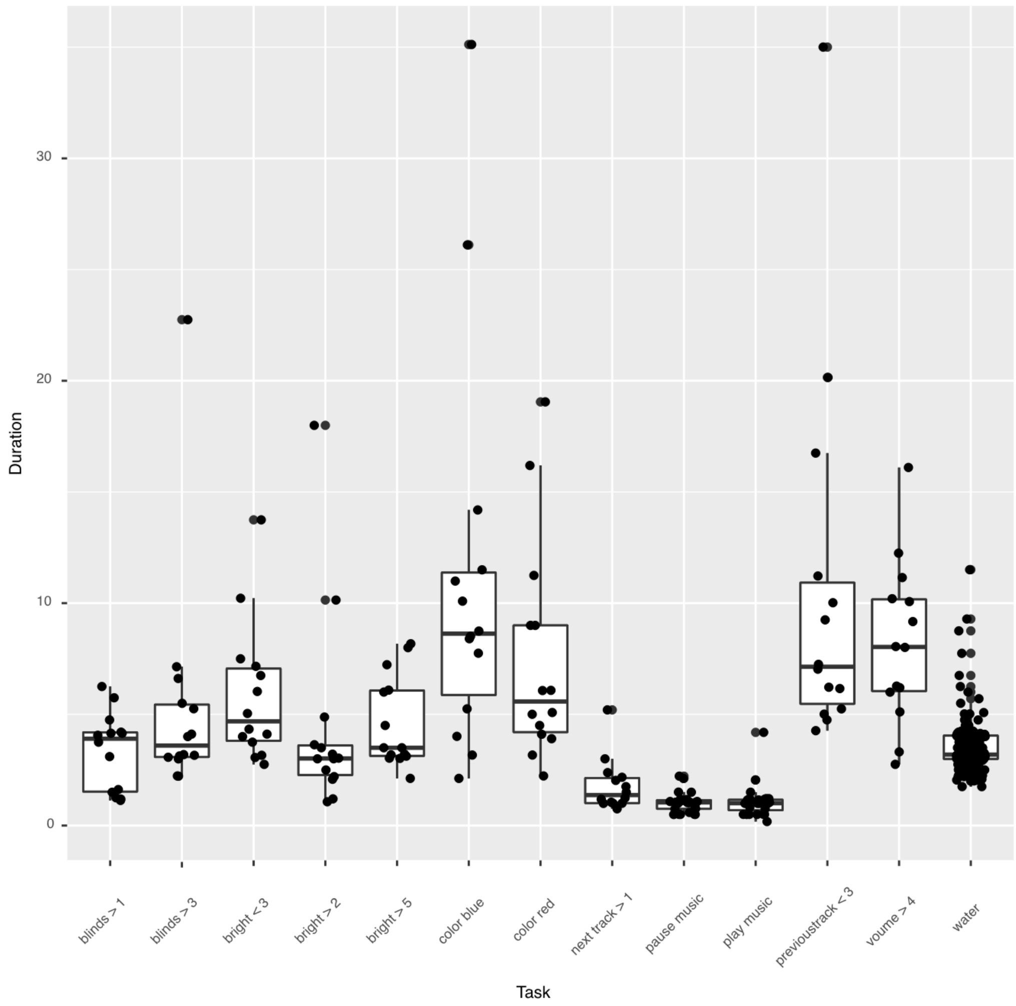


Figure 7: Boxplot of the durations of the secondary tasks

When we removed these data points from the dataset (25 data points) we found no significant difference (P = 0.340) in secondary task duration between the two conditions, although participants were in general slightly slower in the GT condition (3.49s).

Looking more in depth into the individual secondary task duration we see a lot of differences in the individual mean task durations. Table E shows the mean durations of all tasks and the results of a two-sample t-test compared with the durations in the PT condition. from the results we found that the tasks play music, pause music and track > 1 are significantly faster compared with drinking from a bottle while track < 3, volume > 4 are significantly slower.

Task	DF	Mean duration (s)	P
Bright > 5	14	4.61	0.031
Blinds > 3	13	4.04	0.120
Play music	27	0.94	< 0.001
Volume > 4	10	7.59	0.004
Bright > 2	11	3.52	0.483
Track > 1	12	1.42	< 0.001
Pause music	28	1.03	<0.001
Color blue	6	6.12	0.047
Blinds > 1	14	3.34	0.381
Bright < 3	11	5,76	0.027
track < 3	11	6.94	< 0.001
Color red	9	6.01	0.019

Table E: Table showing the mean task durations and the results of the two sample t-test compared with the task durations in the PT condition.

7.2 Subjective data results

After the experiment the participant was asked to fill in a questionnaire with closed and open-ended questions (see table F.)

Closed questions: In the first two questions (see Table D.) the participant had to fill in how its attention was divided during the test in a range from 0-100% between the primary task (vowel counting) and the secondary test in the GT condition (Q1) and the PT condition (Q2). The other questions (Q3-Q9) were closed questions making use of the Likert scale. The Likert scales ranged from 1 = 'Totally not' to 5 = 'very/a lot'. The results in Q1 show us that on average 39.64% of their attention goes to the vowel counting task and 60.36% to the interaction with the glove. When we look at the results of Q2 it shows us that on average 52.14% of their attention goes to the vowel counting task and 47,86% to drinking from the water bottle. When we look at the individual data we see that there are huge differences between the participants answers (90%, 80%, 35%, 40%, 12%, 75%, 10%) which probably means that the question was interpreted differently by the different participants. Furthermore, participants found that the functions and operations with the glove were easy to learn (M = 3.86), but they needed to concentrate a lot when using the glove during the task (M = 3.50). Participants had to concentrate a bit by Selecting a device (M = 2.71) by touching the fingers. Selecting the correct function (E.g., selecting the color function or the brightness function of a lamp) was a little bit harder (M = 3.07) and adjusting the value cost even more attention (M = 3.71). Participants in general did not have the feeling they successfully completed two (Primary and secondary) tasks at the same, in the Device condition. (M=2.43). In the Peripheral condition they felt more that they had successfully completed both tasks at the same time (M=3.93), which implies that multitasking in the periphery was more difficult when using the glove.

#	Questionnaire item	M (%)	SD
1	Specify how your attention was divided between the number of vowels and interacting with the glove	39.64	26.64
2	Specify how your attention was divided between the number of vowels and interacting with the water bottle	52.14	28.27
3	I found the functions and operations with the glove easy to learn	3.86	0.77
4	How much did you have to concentrate on the actions with the glove in general	3.50	0.76
5	How much did you have to concentrate on selecting a device	2.71	1.07
6	How much you had to concentrate on selecting a particular function	3.07	1.00
7	How much did you have to concentrate to adjust a value of a device	3.71	1.27
8	I had the idea that the vibrations while interacting with the glove helped me to concentrate on counting vowels	2.71	1.33
9	I felt that I had successfully completed two tasks at the same time with the prototype	2.43	1.22
10	I felt that I had successfully completed two tasks at the same time with the water bottle	3.93	0.92

Table F: Mean responses of the closed questions

Open questions: Multiple participants answered the question which task requires the most attention changing the color of the lamp. This was visually more demanding and they found it difficult to know where they could find the correct color when rotating the hand. Also, multiple participants mentioned that the rotating movement was too sensitive. Because of that they had to concentrate a lot on rotating because they were afraid to go a step too far and loose count. On the questions which task requires the least attention 10 out of 14 mentioned the play/pause function. This corresponds with the quantitative data.

Observations: During the experiment we recorded the participant so that we could observe them in a later moment. We found that play/pause was really easy. There was almost no disruption and therefore almost did not stop counting. Most people noticeably stopped counting vowels while performing the secondary task. Some people lost count during the GT condition after they performed a task. Some people tried to count further while performing the secondary task with a task like ‘turn up the brightness with 4 steps’. While counting every individual vowel they rotated a bit so they felt at the same time the vibration of the steps, but all participants that tried this technique could not sustain this for a long time. Although before performing the test the instruction was given to look as little as possible to the secondary screen with the light/roller blinds, people almost always looked to the secondary screen. Only when interacting with the music they did not look, but this is because music does not give visual feedback.

From observation, it was also noticeable that the recovery time (time when finishing the secondary task and restarting the primary task) was less while drinking from the bottle in comparison with interacting the glove. Probably because they did not look away from the primary screen with the text.

8. Discussion and conclusions

In this paper, we explored the implementation of a freehand gesture-based interface for peripheral interaction to interact with multiple smart home devices. In this section we will discuss our results and potential shortcomings in our research methodology. Furthermore, recommendations for future research will be made to improve upon this research.

8.1 Measuring peripheral interaction

Measuring if the interactions with the glove are in the periphery is very difficult [25] and from this research we cannot conclude that the interactions are done in the periphery. It takes time, training, and experience to get accustomed to the prototype with its interactions, which can take weeks. To test if the interactions really can become peripheral we need to perform a long term in-situ test. Before participants started the experiment, they got maximum fifteen minutes to train with the glove before starting the experiment. This is far too little time to shift these interactions to the periphery. The comparison of the two conditions gave us interesting results. The vowel count error rate in both conditions showed a significant difference in favor of the Peripheral Condition ($P = 0.01813$). This is not what we expected in our hypotheses. We can conclude from these results that when using our proposed system, the cognitive load, when interacting with the glove, was too high to perform two tasks at the same time successfully. From observations, we noticed that most participants did not count vowels when performing the secondary actions with the glove (GT), while most participants did during the PT condition. We believe this is due to the fact that the primary task was to count vowels and during the secondary task using the glove the participants had to count the number of vibrations; because of this we believe the participant had to use the same mental resources for both tasks making it more difficult to recover from the secondary interaction. It would be interesting to do this experiment with another primary task so that the participant does not have to count in both tasks. When we take a look at the other results we found that there was a significant difference in the mean duration of the tasks in favor of the peripheral task (P= 0.007). although in the GT task participants were slightly slower. This suggests that the interaction with the glove was a bit more disrupting than drinking from a bottle of water. When comparing the mean duration of the secondary tasks the results show us that the interactions with the glove were fast enough to perform in a short amount of time (3.91 seconds) and not significantly slower than drinking from a bottle of water in the peripheral condition (P= 0.340). We can conclude that the interactions with the glove are micro-interactions, which potentially can become peripheral.

8.2 Software improvements

During the experiment the software did not always respond in the right manner or consistently. People mentioned that it was sometimes difficult to adjust a value with only one step because the rotation settings were too sensitive. Because of this, it sometimes took more time to perform the secondary task and more errors. Furthermore, occasionally small bugs appeared when performing actions with the glove. Some participants experienced weird glitches which resulted in some data points we could not use.

8.3 Methodology issues

As mentioned earlier, this experiment is difficult to compare with a real-world situation. In a real-world situation, you change the settings of a device because of an intrinsic motivation. It does not matter if the brightness of the light is 30%, 50% or 70%, you just want enough light to continue with your primary task. During the experiment, the motivation to adjust the value of the brightness was an extrinsic motivation, and changing the value of the brightness did not influence the environment of the primary task. Also, because there was a very specific task, presented in the form of an icon, the participant had to learn the meaning of the icon, had to look at the icon when it appeared and had to transform this to an action. In the peripheral condition the participant only saw one icon appearing every time (icon of a bottle). Because of this, the participant did not have to think of the meaning of the icon and also to focus visually on the icon at all. Although the tasks in both conditions were not intrinsic motivations, the secondary task in the Glove Condition could have taken more time because it adds cognitive load. Furthermore, the tasks to set the values on an exact level makes that the participants started counting the number of steps he rotated. Because of this we believe that some interactions became too precise and that the participants was very focused on performing the task successfully.

When we look at the data of the secondary tasks in the Devices condition in where the participant did not have to count, like the ‘play', ‘pause’ and the ‘next track’ interaction, we see that those interactions were much faster than the other interactions with less disruption when performing these tasks and less differences in duration between the participants. To improve the experiment with this in mind, we could for example darken the text slowly, so that it will be unreadable, or change the background color so that the text and the background mismatch and the participant has to change the settings using the glove to be able to read again. In this case the participant does not have to count in the secondary task and the motivation to change a setting will be more intrinsic.

8.4 Conclusions

Based on the results, we gained some insights into the design of gesture-based interfaces for peripheral interaction for smart home related tasks.

1. We found that precise gestural interactions are harder to perform in the periphery and affect the performance. This is in line with other research [31].
2. facilitating as few gestures as possible has a positive effect on learnability. People do not have to think about it. Leaving more mental resources for the primary task.
3. Results suggest that micro hand gestures such as tapping, double-tapping, and rotating, are a suitable interaction type for peripheral interaction. Double-tapping
4. Results indicate that the use of spatial memory, by connecting functions to limbs such as fingers, make it very easy to learn and to remember them.
5. Adding multiple functions to one finger makes it more difficult to recall them.
6. Tactile feedback provides good reference points during gestural interactions such as rotating. Especially, when devices do not give immediate functional feedback, such as roller blinds, which are rather slow. The haptic feedback helps the participant to shift back their attention more quickly to the primary task.

Future research

For future research, it would be interesting to investigate the difference between a virtual smart home environment, like we used for this experiment, and the use of real smart home devices. The ambient nature of real smart home devices could have an effect on the results. Also a long term in-situ experiment should be conducted to study if our proposed system could be used in the periphery.

We did not experiment with different kinds of gestures, levels of preciseness and subtle changes in the vibrotactile feedback. This could further be investigated.

In our experiment the participant had the ability to perform six different actions with three smart home devices. It would be interesting to study how many different actions can be performed in the periphery and with how many devices.

Furthermore, the study we have done was focused on using the dominant hand, but what is the effect of using the non-dominant hand? When the non-dominant hand can be used to perform peripheral interactions, the dominant hand can be used to perform actions concerning a high demanding task.

References

1. "Golden Krishna – The Best Interface Is No Interface." YouTube, YouTube, 29 Apr. 2016, www.youtube.com/watch?v=9Da7IhgaP2Y.
2. McLuhan, Marshall, 1911-1980. Understanding Media; the Extensions of Man. New York :Signet Books, 1966. Print.
3. Bakker, S., van den Hoven, E., and Eggen, B. Acting by hand: Informing interaction design for the periphery of people's attention. Interact Comput 24, 3 (2012), 119-130.
4. Weiser M, Brown JS (1997) The coming age of calm technology. In: Denning PJ, Metcalfe RM (eds) Beyond calculation: the next fifty years of computing. Springer, New York, pp 75–85
5. Heijboer, Marigo, et al. "Facilitating peripheral interaction: design and evaluation of peripheral interaction for a gesture-based lighting control with multimodal feedback." Personal and Ubiquitous Computing 20.1 (2016): 1-22.
6. Bakker, Saskia, Elise Van Den Hoven, and Berry Eggen. "Acting by hand: Informing interaction design for the periphery of people's attention." Interacting with Computers 24.3 (2012): 119-130.
7. Fitzmaurice, George W., Hiroshi Ishii, and William Buxton. "Bricks: laying the foundations for graspable user interfaces." CHI. Vol. 95. 1995.
8. Ishii, Hiroshi, and Brygg Ullmer. "Tangible bits: towards seamless interfaces between people, bits and atoms." Proceedings of the ACM SIGCHI Conference on Human factors in computing systems. ACM, 1997.
9. Ishii, Hiroshi, et al. "ambientROOM: integrating ambient media with architectural space." CHI 98 conference summary on Human factors in computing systems. ACM, 1998.
10. Wensveen, Stephan AG, Johan Partomo Djajadiningrat, and C. J. Overbeeke. "Interaction frogger: a design framework to couple action and function through feedback and feedforward." Proceedings of the 5th conference on Designing interactive systems: processes, practices, methods, and techniques. ACM, 2004.
11. Fitzmaurice, George W., and William Buxton. Graspable user interfaces. University of Toronto, 1997.

12. Bakker, Saskia. "Design for peripheral interaction." Eindhoven University of Technology 184 (2013).
13. Ashbrook, Daniel Lee. Enabling mobile microinteractions. Diss. Georgia Institute of Technology, 2010.
14. Loclair, Christian, Sean Gustafson, and Patrick Baudisch. "PinchWatch: a wearable device for one-handed microinteractions." Proc. MobileHCI. Vol. 10. 2010.
15. Hudson, Scott E., et al. "Whack gestures: inexact and inattentive interaction with mobile devices." Proceedings of the fourth international conference on Tangible, embedded, and embodied interaction. ACM, 2010.
16. Harrison, Chris, Desney Tan, and Dan Morris. "Skinput: appropriating the body as an input surface." Proceedings of the SIGCHI conference on human factors in computing systems. ACM, 2010.
17. Dezfuli, Niloofar, et al. "PalmRC: imaginary palm-based remote control for eyes-free television interaction." Proceedings of the 10th European conference on Interactive tv and video. ACM, 2012.
18. Kim, David, et al. "Digits: freehand 3D interactions anywhere using a wrist-worn gloveless sensor." Proceedings of the 25th annual ACM symposium on User interface software and technology. ACM, 2012.
19. Gustafson, Sean, Christian Holz, and Patrick Baudisch. "Imaginary phone: learning imaginary interfaces by transferring spatial memory from a familiar device." Proceedings of the 24th annual ACM symposium on User interface software and technology. ACM, 2011.
20. Huang, Da-Yuan, et al. "DigitSpace: Designing Thumb-to-Fingers Touch Interfaces for One-Handed and Eyes-Free Interactions." Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems. ACM, 2016.
21. Freeman, Euan, Stephen Brewster, and Vuokko Lantz. "Interactive light feedback: Illuminating Above-Device gesture interfaces." IFIP Conference on Human-Computer Interaction. Springer, Cham, 2015.
22. Lissermann, Roman, et al. "Earput: Augmenting behind-the-ear devices for ear-based interaction." CHI'13 Extended Abstracts on Human Factors in Computing Systems. ACM, 2013.
23. Hausen, Doris, et al. "Evaluating peripheral interaction." Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction. ACM, 2014
24. 2. Olivera, Fernando, et al. "Do not disturb: physical interfaces for parallel peripheral interactions." IFIP Conference on Human-Computer Interaction. Springer, Berlin, Heidelberg, 2011.

25. Hausen, Doris, et al. "Comparing input modalities for peripheral interaction: A case study on peripheral music control." IFIP Conference on Human-Computer Interaction. Springer, Berlin, Heidelberg, 2013.
26. Probst, Kathrin, et al. "A chair as ubiquitous input device: exploring semaphoric chair gestures for focused and peripheral interaction." Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM, 2014.
27. Wickens, Christopher D, and Jason S. McCarley. Applied Attention Theory. Boca Raton: CRC Press, 2008. Print.
28. Kahneman, Daniel. Attention and effort. Vol. 1063. Englewood Cliffs, NJ: Prentice-Hall, 1973.
29. Wickens, Christopher D., and Jason S. McCarley. Applied attention theory. CRC press, 2019.
30. Bakker, Saskia, and Karin Niemantsverdriet. "The interaction-attention continuum: considering various levels of human attention in interaction design." International Journal of Design 10.2 (2016): 1-14.
31. Bakker, Saskia, and Karin Niemantsverdriet. "The interaction-attention continuum: considering various levels of human attention in interaction design." International Journal of Design 10.2 (2016): 1-14.
32. Bakker, Saskia, Doris Hausen, and Ted Selker, eds. Peripheral Interaction: Challenges and Opportunities for HCI in the Periphery of Attention. Springer, 2016.
33. Hausen, Doris, et al. "StaTube: facilitating state management in instant messaging systems." Proceedings of the Sixth International Conference on Tangible, Embedded and Embodied Interaction. ACM, 2012.
34. Probst, Kathrin, et al. "A chair as ubiquitous input device: exploring semaphoric chair gestures for focused and peripheral interaction." Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM, 2014.
35. Loehmann, Sebastian. "On the Relevance of Freehand Gestures for Peripheral Interaction." Peripheral Interaction: Embedding HCI in Everyday Life: 15.
36. Hausen, Doris. "Peripheral interaction: facilitating interaction with secondary tasks." Proceedings of the Sixth International Conference on Tangible, Embedded and Embodied Interaction. ACM, 2012.
37. Oulasvirta, Antti, et al. "Interaction in 4-second bursts: the fragmented nature of attentional resources in mobile HCI." Proceedings of the SIGCHI conference on Human factors in computing systems. ACM, 2005.