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RWTH AACHEN UNIVERSITY

# *Investigating Modalities for Supplemental Notifications in Online Presentations via a Wrist-Worn Device*

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# Abstract

During the last few years, the importance of videoconferencing has increased significantly. The switch to digital platforms for lectures and meetings has become commonplace in both the private and business spheres. Additionally, the COVID-19 pandemic has shown that digital meetings are not only a daily communication tool but also a crucial part of our life which allows us to maintain a wide variety of interaction means.

However, there is a problem that can be determined as a face-to-face interchange loss tendency. Especially for presenters, non-verbal cues from the audience are limited. The constraints of existing videoconferencing platforms exacerbate this problem. These are primarily presented in visual form on the screen. To improve the experience in digital conferences and reduce the visual load of the user, we investigate further possibilities for notification techniques. We intend to provide feedback for users not only through the visual channel but also through haptic or auditory channels.

For this purpose, we developed a prototype in the form of a wristband. This wristband enables the transmission of information using visual, haptic, and auditory signals. We conducted a study with 16 participants in order to investigate the usefulness of the device for the users. This study analyzed, among other things, the effectiveness of the device, the user experience, and the workload. Therefore, the signals coming from the wrist-worn prototype were compared to the visual notifications already integrated into the video platform Zoom. The results indicate that the users could perceive the presented signals from the wristband in a better and more pleasant way. Splitting the signals across different sensory channels also significantly reduced cognitive load.

# Überblick

Die Bedeutung von Videokonferenzen hat in den letzten Jahren stark zugenommen. Das Ausweichen auf digitale Plattformen für Vorträge und Treffen ist heutzutage sowohl im privaten als auch im geschäftlichen Bereich zum Alltag geworden. Zusätzlich hat die COVID-19 Pandemie gezeigt, dass diese digitale Treffen nicht nur möglich, sondern auch notwendig sind, um verschiedenste Interaktionen und Kommunikationen aufrecht erhalten zu können.

Ein bestehendes Problem ist jedoch, dass ein Großteil des persönlichen Austausches verloren geht. Vor allem für vortragende Personen sind die Möglichkeiten nonverbale Signale des Publikums zu erhalten und wahrzunehmen reduziert. Dies wird durch die begrenzten Instrumente der existierenden Plattformen für Videokonferenzen verstärkt. Diese werden meistens in visueller Form auf dem Bildschirm dargestellt. Um das Erlebnis in digitalen Konferenzen zu verbessern und die visuelle Auslastung des Nutzers zu reduzieren, untersuchen wir weitere Möglichkeiten für Benachrichtigungstechniken. Diese sollen den Nutzern nicht nur auf visuellem Weg, sondern auch auf haptischen oder auditiven Kanälen Optionen bieten, Rückmeldungen zu erhalten.

Für diesen Zweck wurde in dieser Arbeit ein Prototyp in Form eines Armbandes entwickelt. Dieses Armband ermöglicht die Übermittlung von Informationen durch visuelle, haptische und auditive Signale. Um den Nutzen für die Anwender zu untersuchen, haben wir eine Studie mit 16 Probanden durchgeführt. In dieser Studie wurden unter anderem die Effektivität des Gerätes, die Benutzererfahrung und die Arbeitsbelastung analysiert. Dazu wurden die vom Armband ausgehenden Signale mit den bereits integrierten visuellen Benachrichtigungen in der Videokonferenzplattform Zoom gegenübergestellt. Die Ergebnisse deuten darauf hin, dass die Nutzer die gegebenen Signale und Rückmeldungen durch das Armband besser und angenehmer wahrnehmen konnten. Die kognitive Belastung wurde durch die Aufteilung der Signale auf verschiedene sensorische Kanäle zudem deutlich reduziert.

# Acknowledgements

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Lastly, I would like to thank my friends for their mental support. Especially, I want to thank Florian Hunecke and Fabian Bannier for their advice and motivation.

# Conventions

Throughout this thesis we use the following conventions.

*Text conventions*

Source code and implementation symbols are written in `typewriter-style text`.

The whole thesis is written in American English.

The singular ”they” refers to unidentified third persons.

# Chapter 1

# Introduction

Public speaking is a fundamental part of everyday work in academic and educational fields: for professors, students, and researchers, as well as in the industrial sector. Presenters often explain concepts, ideas, and projects to their audiences or inform their colleagues about the latest results and findings. Especially in recent years, due to the pandemic (COVID-19), it has become increasingly common to hold presentations and lectures online "in front of a monitor". However, online meetings are not a complete substitution and effective adaptation for real conferences and meetings where audience feedback is either very limited or missing [Murali et al., 2021, Lee et al., 2022]. Face-to-face meetings are more personal, interactive, and authentic than online meetings, where communication bandwidth is limited and non-verbal social cues are difficult to recognize [Lee et al., 2022]. Murali et al. discovered in their research that 83% of surveyed employees at a large technology company miss audience feedback during online presentations. Getting feedback from the listeners is necessary to guarantee that the information is delivered and to keep the audience involved and attentive [Hassib et al., 2017]. Therefore, the lack of audience feedback is a potential source of anxiety in public speaking [MacIntyre et al., 1997].

During the last few years, the importance of videoconferencing has increased significantly.

These problems are related to the constraints of today's videoconferencing applications, which provide limited screen space to presenters, significantly impacting the

The visual sensory channel is overloaded while presenting due to the limitations of existing video conferencing platforms.

potential of online communication [Murali et al., 2021]. Computer interfaces are usually based on visual feedback for providing information to users [Freeman et al., 2017]. Presenting online is a highly cognitive task, where visual perception is often overloaded [Murali et al., 2021]. It is common for video conferencing application tools such as *Zoom*[1] that chat questions from the audience or other user reactions tend to be unnoticed, as presenters focus all of their attention on their talk, and hence on their slides.

Using different notification modalities can lead to a better user experience and reduce perceptual load.

However, the interaction between the user and the device can also be carried out and enhanced using other human senses or capabilities. Using different notification modalities can lead to a better user experience by more effectively grabbing peoples' attention [Lazaro et al., 2021]. If one modality is occupied or unavailable, another one can be used to ensure successful interaction with the interface [Freeman et al., 2017]. Many applications integrating additional haptic and auditory feedback are based on Wickens' theory [Wickens, 2002]. The main idea is that in user interaction design, it is essential to distribute different tasks across sensory modalities to reduce perceptual load and improve task performance [Freeman et al., 2017, Wickens, 2002]. The delivery of notifications depends on many aspects, such as individual user preferences, the ongoing task and environmental influences [Lazaro et al., 2021]. Thus, when examining how notifications should be designed, the specifics and context of the task need to be considered.

Despite a large body of literature on the exploration of notification, research on notifications in an online meeting environment is quite limited.

Research in this field investigated haptic communication using a handheld device to provide assistive cues to the speaker Tam et al. [2013], visual feedback modalities by displaying notifications on an ambient display in a smart home context Voit et al. [2021], or by using light illumination as a subtle notification mechanism Pohl et al. [2016]. Combinations of different sensory modalities have also been studied to improve access for people with visual impairments Vitense et al. [2002] or to present notifications in an augmented reality environment Lazaro et al. [2021]. Despite a large amount of literature on notifications, research focusing on presenting notifications in an online meeting environment is quite limited. Most studies have concen-

[1]https://zoom.us/ (*Accessed: November 7, 2022*)

trated on face-to-face meetings [Tam et al., 2013, Damian and André, 2016]. Therefore, with this work, we aim to investigate the problem of the overloaded visual modality in online presentations to improve the presenter's experience. We want to focus on the impact of the different notification modalities without interfering with the attention span of the presenter. Specifically, we explore and evaluate the effectiveness, user experience and the users' workload of the main communication feedback modalities, such as *visual*, *auditory*, and *vibrotactile* feedback, on a *wrist-worn* device. In situations where users need to devote their total concentration to their primary activity, for example, during a presentation or while driving, notifications on wearable devices, such as smartwatches, can be a valuable alternative for conveying supplementary information to users [Graham-Knight et al., 2020].

We conduct a user study to investigate different modalities of the wrist-worn device.

Therefore, we conduct a user study to explore the use of a wearable device on the wrist to deliver supplemental notifications during online presentations. We compare the visual notifications already integrated into *Zoom* with the additional notifications coming from our wrist-worn prototype. We want to explore how presenters perceive different notification types and interpret and process their meanings while engaged in a primary task, such as giving a presentation. Our results can help understand the impact of wrist-worn notifications on visual attention and mental workload and could improve presenter performance and digital collaboration in online meetings.

## 1.1 Outline

This work is organized as follows:

**Chapter 2** gives an overview of research work that relates to the topic of this thesis, in particular different notification modalities, challenges of public speaking, and possible information placements.

**In Chapter 3,** we will present the selected notification modalities for our own wrist-worn prototype focusing on providing additional information during online presentations.

Next, **in Chapter 4** we present an experiment with 16 participants: we investigated how users perceive and interpret notification techniques involving different modalities.

**In Chapter 5**, we will summarise our conclusions and reveal further ideas for future work.

# Chapter 2

# Related work

In this Chapter we are going to give an overview on already conducted research that has investigated the effects of different modalities for presenting notifications while executing a primary task. Then we address the public speaking context and the challenges that people have encountered in the last two years of the pandemic. Moreover, we will take a look at the possible placements for supplemental notifications during online meetings and illustrate what motivated us to investigate the communication via a wrist-worn device.

## 2.1 Notifications Modalities in HCI

Notifications grab the user's attention by actively providing current information.

Notifications are intended to grab the users' attention through the active provision of information [Iqbal and Bailey, 2011, Pielot et al., 2018]. This information comes in a variety of different forms, which we generally process through our different senses [Wallace and Stevenson, 2014]. The channels we use to perceive the events and objects around us are sensory modalities - sight, hearing, touch, smell, and taste. Current interactive systems utilize notifications to inform users of incoming messages or upcoming appointments, updates, and reminders.

**Figure 2.1:** Modalities from left to right: Abstract Visual, Audio, Tactile, Olfactory. Figure taken from Warnock et al. [2011].

The number of notifications is constantly increasing due to the rise of mobile and desktop applications [Roumen et al., 2015, Pielot et al., 2014].

Disabling notifications can lead to anxiety and stress.

Desktop notifications can be beneficial in many situations but at the same time, permanently appearing pop-up messages or short sound alerts can also be distracting and straining [Rzayev et al., 2019]. However, completely disabling notifications could lead to restlessness and stress because people are afraid of missing important information [Pielot and Rello, 2015, Rzayev et al., 2019]. Consequently, during online meetings, it is necessary to keep the presenter aware of incoming notifications, but at the same time, without distracting from the primary task.

### 2.1.1 Notifications in a Smart Home Context

Notifications can affect the performance of primary tasks.

Notifications play a central role in conveying important and up-to-date information. However, the fact that notifications affect the performance of primary tasks and potentially lead to unwanted consequences has been known for a long time [Voit et al., 2021, Lazaro et al., 2021]. For several years, researchers have been focusing on the impact of different notification techniques in smart home environments [Vastenburg et al., 2009, Warnock et al., 2011, Voit et al., 2021].

Warnock et al. [2011] investigated each of the human senses except taste - sight, smell, hearing and touch - to find out which of these modalities would be most suitable for providing information to users in the home environment. They compared standard traditional notifications in the form of text and pictograms with notifications that use these four human senses. In the experiments performed, text and icons appeared on the top of the laptop screen. The visual channel was represented by an abstract peripheral light, displayed on the wall next to the participant via a projector. Sound notifications were transmitted through headphones, while touch was stimulated through the signals of a vibrotactile actuator attached to the wrist. Olfaction was stimulated by a fan-driven device spreading different smells. All of the above mentioned communication techniques used in the study are shown in Figure 2.1. For the user study Warnock et al. chose a computer card-matching game, requiring a high level of concentration. During each game participants received notifications at random intervals. Responding to the incoming stimuli by pressing buttons was a secondary task. The results indicated that response accuracy and response time for the visual and auditory modalities were higher than for the tactile and olfactory modalities. The main findings of this study are as follows: (1) on the one hand the modalities do not affect the performance of the primary task, but (2) on the other hand they do affect the perception of incoming notifications [Warnock et al., 2011].

According to Warnock et al. [2011], the modalities affect the perception of incoming notifications but not the performance of the primary task.

### 2.1.2 Notifications in Augmented Reality

This approach of comparing different modalities to gather people's interpretation and experience, but here in the context of augmented reality, was used in the research work of Lazaro et al. [2021]. Augmented Reality (AR) stands for new intelligent systems that combine real world and virtual objects to change the perception of environments and provide additional information about the surroundings. AR technology can be used not only with mobile devices but also with head-mounted displays. Lazaro et al. [2021] explored interaction with this kind of device. Similar to computer and laptop displays, AR head-mounted displays (HMD) have a quite limited space for interaction, which can lead to problems regarding traditional pop-up notifications by interrupting and disrupting the user's ongoing task.

Lazaro et al. [2021] explored visual, auditory, and multimodal modalities for presenting notifications within the AR system.

The notification modalities used in this study were represented by visual, auditory, and multimodal channels. Visual notifications appeared as a red bell-shaped icon in the upper corner of the screen in the user's field of view. The auditory channel was triggered by a sound similar to the familiar notification tone in mobile phones. The multimodal communication combined the two modalities described above. The primary task involved the process of searching for items in AR and classifying them into categories. In the meantime, participants had to respond to randomized alerts. Recognition rate, user preferences, and task performance were measured for each modality [Lazaro et al., 2021].

In their study, a combination of visual and auditory modalities achieved the shortest response time.

The key findings showed that the combination of auditory and visual notifications were recognized faster compared to the other two unimodal notification techniques. The majority of participants preferred multimodal notifications. It was observed that the auditory signal attracted users' attention, while the visual signal was used only for confirmation [Lazaro et al., 2021]. About 50% of the notifications were not detected in unimodal condition. This can be explained by the occupation of the visual channel while focusing on the primary task. According to Lazaro et al., "visual cues alone may not be an appropriate notification signal for in-system AR tasks" [2021].

## 2.2 Public Speaking

Public speaking is a highly cognitive task that requires concentration and attention.

As for public speaking, it is essential to acknowledge that presenting in front of an audience requires a high level of attention and concentration [Tam et al., 2013, Murali et al., 2021]. During oral presentations, presenters usually need to control their voice and intonation, speech content, and the effective use of non-verbal cues [Chen et al., 2015]. Monitoring these qualities and providing additional attention to the audience indicate that public speaking is a highly cognitive task [Tam et al., 2013]. In fact, even experienced presenters face an overload of visual and aurally sensory channels [Tam et al., 2013].

Public speaking is an important skill in professional careers as well as in education [Lee and Kleinsmith, 2019]. The COVID-19 pandemic resulted in a dramatic change in industrial and academic fields. It has caused a shift from face-to-face meetings to digital meetings. In order to be able to continue work activities without physical contact, the use of online video conferencing tools has increased rapidly [Lee et al., 2022].

Lee et al. analyzed the problems people have encountered in video conferencing over the past two years.

Over the past two years of experience with the videoconferencing applications, users have encountered many challenges associated with online meetings [Lee et al., 2022, Kimani et al., 2021]. Lee et al. analyzed unmet user needs with 167 problematic situations in online conferencing. The authors looked at potential new design directions to improve the quality and experience of video conferencing. For this purpose, numerous interviews were conducted in *Zoom* with people who had participated in at least 50 video conferences during the pandemic. Participants shared their experiences, distracting moments, and specific needs from their perspectives. As a result, unintentional user actions, such as starting a presentation without screen sharing, revealing personal information, speaking on mute or forgetting to turn off the sound, and extraneous noise are the most common distracting factors for users [Lee et al., 2022]. Participants also mentioned distracting experiences related to the usability of the videoconferencing tool. One participant reported constantly missing messages in the chat, when sharing the screen. In addition, participants have often complained that they do not have another option to inform other participants about their current status without interrupting the meeting.
The researchers were also interested in participants' assumptions about whether they would continue to use videoconferencing platforms in the post-covid period. 72% of the respondents are confident in the continued active use of these applications. According [Lee et al., 2022], a key finding is that "users have high expectations and demands for technologies and designs that current video conferencing tools do not support" [Lee et al., 2022].

Due to the pandemic, it has also become clear that some jobs that previously had to be done in the office can actually be done remotely [Sytch et al., 2020]. This indicates a further need to investigate the video conferencing in order to improve the user experience. For several years, numerous systems have been developed to support presenters. However, most of the studies have concentrated on face-to-face meetings [Tam et al., 2013, Damian and André, 2016]. When giving in-person presentations, presenters speak in front of a real audience in the same room. In contrast to online presenters, they have a significantly larger field of view and have direct access to the listeners, enabling them to immediately perceive visual cues (e.g., raised hands, facial expressions) and auditory cues (e.g., volume in the room, verbal responses) from the audience.

In contrast to online meetings, presenters have direct contact with the audience during face-to-face conferences, allowing them to receive immediate feedback from listeners.

Regarding the field of videoconferencing, many researchers have focused on developing systems that imitate the experience of face-to-face meetings. In order to create a more realistic experience during a video conference Mehrotra et al. [2011] designed a system that allowed the spatial adaptation of outgoing sounds depending on the participant's position. Murali et al. [2021] used neural networks to analyze human facial expressions and head gestures of online meeting members to highlight the most active participant as additional real-time feedback for the presenter.

However, previous studies have not investigated the problem of the overloaded visual channel while giving a presentation online. Video conferencing tools, in general, provide information to users in a single sensory modality in the form of visual notifications. A poor or insufficient use of sensory modalities in information transmission can lead to loss of data and frustration. One possible method for not overloading the feedback modality used for the primary task and providing a reliable notification system is to examine other sensory modalities [Kotowick and Shah, 2017].

## 2.3 Information placement

When developing supplementary notifications for presenters, an optimal placement needs to be discovered that would allow users to stay up-to-date without being distracted from the primary task.

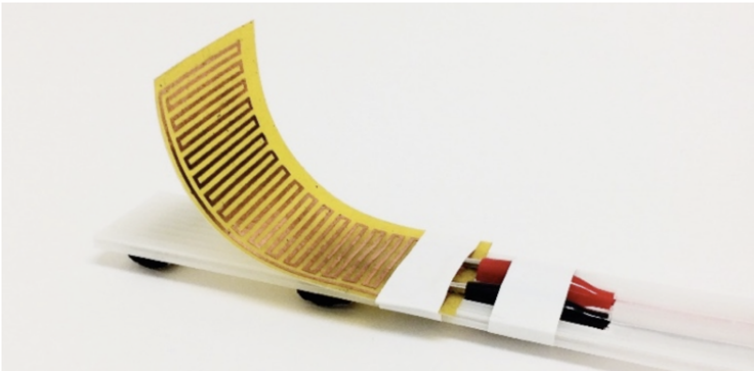

**Figure 2.2:** Shape changing notifications. Figure taken from [Jones et al., 2017].

### 2.3.1 Peripheral Locations

Staying concentrated and yet being informed are usually in conflict with each other. One solution to solve this problem is to take advantage of peripheral vision [Raudanjoki et al., 2020]. In a research conducted by Jones et al. [2017], near and far peripheral locations were compared to determine the optimal location for shape changing notifications. Their purpose was to investigate an alternative, non-distracting way for notifying people working on a computer about non-urgent information. Jones et al. [2017] followed calm technology, the idea of which is that technologies are less distracting when information is transmitted at the periphery [Weiser and Brown, 1997]. The prototype used for shape changing notifications is depicted in Figure 2.2. This small 5cm x 13cm device changes its shape from flat to lifted in 20 seconds when electrical current is applied.

The transmission of information in the periphery of human vision is less distracting from the primary task.

They conducted a user study to test the effect of these notifications and to find out which location should be preferred depending on a person's main task. The device was placed on the participant's desk near the laptop. Two different locations were investigated: near and far locations, as shown in Figure 2.3. The primary task involved solving arithmetic problems, and the secondary task required responding to incoming notifications.

Jones et al. [2017] investigated near and far peripheral locations for shape changing notifications.

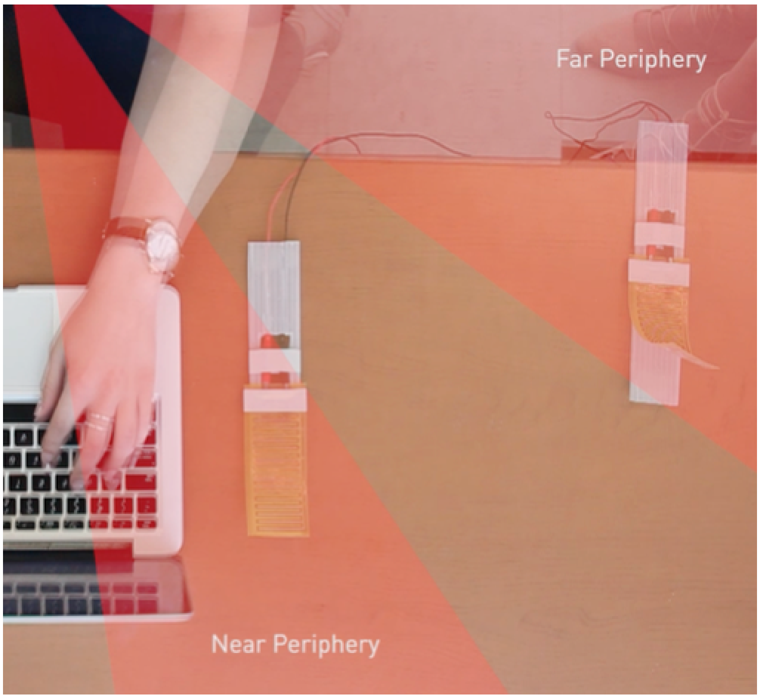


**Figure 2.3:** The apparatus on the participant's desk for the user study. Figure taken from [Jones et al., 2017].

According to the results, the near periphery is a beneficial and applicable information placement for achieving the following criteria:

- Users are not distracted from the main task
- Notifications are easily detected

### 2.3.2 Wrist Location

In recent years, there has been considerable interest in wearable interaction devices. One of the most perspective and commonly used locations for interaction on the human body is the wrist [Pohl et al., 2016]. The fact that smartwatches resemble conventional wristwatches, both in terms of where they are worn on the body and their visual appearance, led to quick social acceptance as new technical

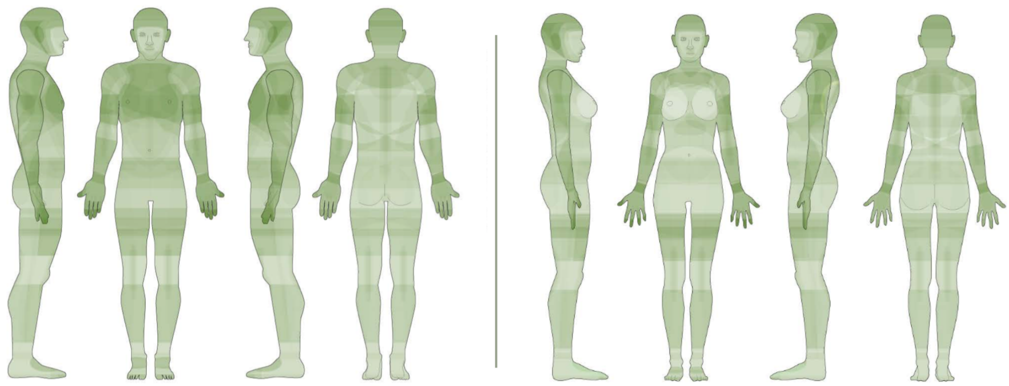

**Figure 2.4:** Body map. The darker the green is the more likely a device should be placed on the body in the location. Image adapted from Zeagler [2017].

devices. Modern smartwatches typically use visual and vibrotactile feedback for user interaction [Pohl et al., 2016]. Because of the close and direct contact with the skin, the area around the wrist provides an ideal location for haptic communication.

Positioning on the wrist is suitable for direct transmission of haptic signals.

The entire wrist can be involved in an interaction to transmit information. This offers a possibility to provide haptic feedback over the complete area. A wrist-worn device has already been used to study human perception of thermal feedback [Freeman et al., 2017]. Furthermore, this on-body location has been utilized by Hong et al. [2017] to assist people with visual impairments. They integrated multiple vibration motors into a wristband for hand-guided navigation. Another application for wrist-based haptic feedback was discovered in the context of face-to-face presentations. Tam et al. [2013] have developed a handheld device that provides tactile cues to the speaker during the presentation to facilitate time management.

Regarding visual feedback, it is necessary that visual cues on wearable devices can always be detected. Harrison et al. [2009] examined different body locations to determine where wearable devices should be placed. They developed small sensor-displays with flashing LED lights to send visual stimuli. The sensors were attached to seven positions: shoulder, chest, upper arm, waist, wrist, thigh and feet. According to Zeagler [2017] body map (shown in Figure 2.4), the majority of the positions considered in this study correspond to the most popular locations for wearable technology.

The wrist location is visible while reading, typing, and gesturing in conversation.

The participants within this study were asked to press the button on the displays as quickly as possible when the blinking light was noticed. During the study period (about two hours), almost all participants were either working on the computer or reading. The wrist position achieved the best results showing the shortest response time and the lowest error rate. As stated by Harrison et al. [2009], this location seemed to be the most visually accessible during reading, typing, and gesturing in conversation.

# Chapter 3

# Notification Modalities on the Wrist

Before presenting our wrist-worn prototype and the notification design, we first discuss the modalities we chose for exploring supplemental notifications during online meetings.

## 3.1 Choice of Notification Modalities

Most information is processed through the visual channel.

Vision is our most important and complex sensory modality. Most information is processed through this sensory channel. Thus, visual feedback is particularly prevalent in human-computer interaction. Today's videoconferencing tools generally use only unimodal visual feedback provided on the display, which could lead to an overload of the visual sensory channel and cognitive processing capacities.

We want to consider visual feedback forms different from traditional visual notifications.

However, notifications involving the visual channel for communication can be presented in many different ways. We are interested in considering visual feedback as an information delivery mechanism in a form different from traditional digital notifications on the screen. According to the research presented in Section 2.3.1, placing the notification in the near periphery is suitable for situations where one needs to focus on the primary task without being distracted by the notifications.

Haptic feedback has been used in previous research to provide supportive cues to presenters.

The user-device interaction could also be improved using other human senses. If one modality is occupied, another one can be used to reduce perceptual load and improve task performance [Freeman et al., 2017]. Therefore, it is essential to explore other possible notification modalities. Tam et al. [2013], Damian and André [2016] investigated the potential of real-time haptic feedback for the presenter during face-to-face meetings. Both studies show that vibrotactile feedback is a viable candidate for the communication during a presentation, as the speakers do not have to focus their field of view on the feedback device.

Auditory modality can be used for conveying important messages.

Auditory feedback also has great potential to enrich the user-device communication during tasks that orient a user's attention visually. The previous research has demonstrated that non-speech audio can be used for contextually important messages [Freeman et al., 2017]. Based on the research findings in Section 2.1.2, the multimodal feedback combining auditory and visual notifications was recognized faster and preferred compared to the unimodal information delivery mechanism. According to Lazaro et al. [2021], the non-speech audio signals are essential for notification recognition.

Regarding the human sense of smell, we have not included the olfactory feedback in our further investigation. Existing research demonstrates that notifications stimulating olfaction are not yet efficient enough for communication requiring immediate action by the user [Dmitrenko et al., 2017].

## 3.2 Wrist-Worn Prototype

We developed a wrist-worn prototype to explore different modalities.

We created a hardware prototype for incoming notifications in order to investigate the different modalities on the wrist-worn device. Our prototype consists of three main components: a NeoPixel ring, a vibration motor and a piezo element, shown in Figure 3.1. Each component is designed to be perceived either by sight, hearing or touch.

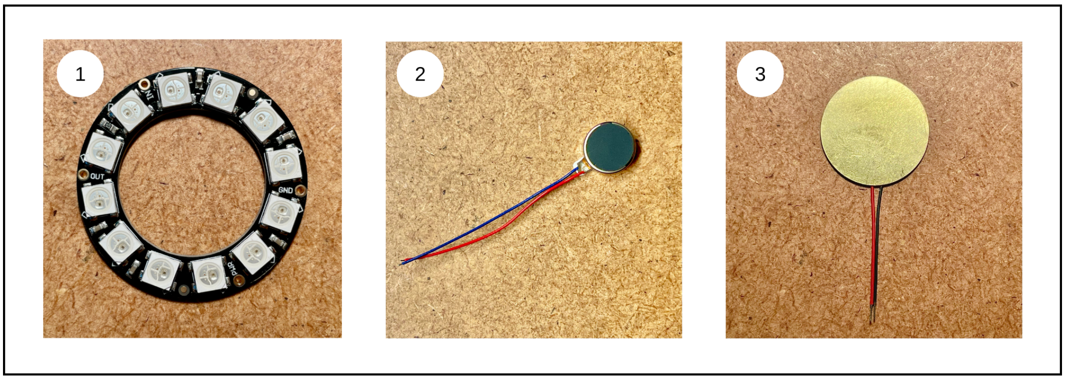


**Figure 3.1:** Main components: (1) NeoPixel Ring, (2) Vibration Motor, (3) Piezo Buzzer.

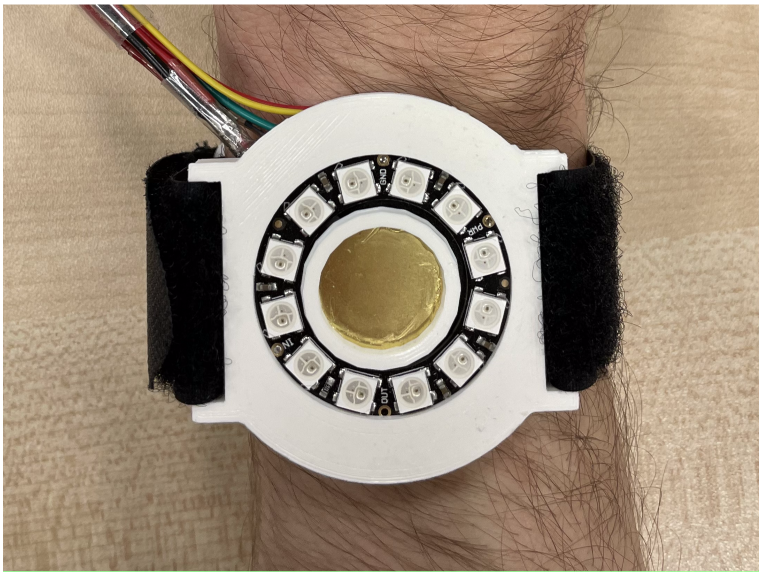

**Figure 3.2:** Wrist-worn prototype.

Adafruit's[1] NeoPixel ring with 12 LEDs was chosen to generate *visual* stimuli. The LEDs are arranged in a circle with an outer diameter of 37mm. For the *haptic* feedback, we used a 10mm x 3mm vibration motor, located under other components to be in closer contact with the skin. *Auditory* feedback was provided by a 27mm diameter piezo element. In Figure 3.3 a schematic is shown for connecting the above described components to an Arduino Uno microcontroller.

Our prototype consists of three main components: an LED ring, a vibration motor, and a piezo element.

[1]https://www.adafruit.com (*Accessed: November 7, 2022*)

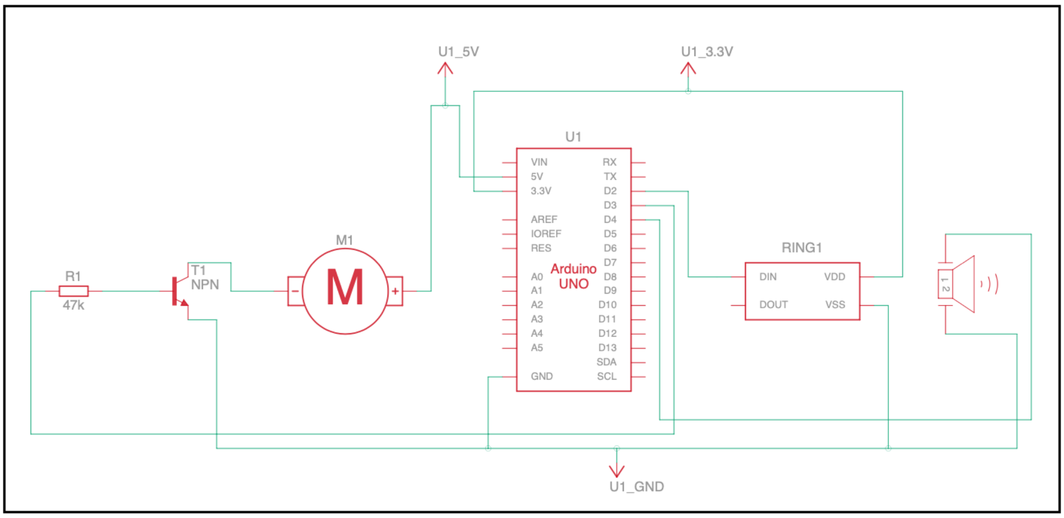


**Figure 3.3:** Schematic view of the wrist-worn prototype. The schematic was created by the 3D design modeling tool Tinkercad[a].

[a]https://www.tinkercad.com (*Accessed: November 7, 2022*)

We designed our device similar to a conventional wristwatch.

Based on the findings of the research in Section 2.3.2 that the wrist provides a unique opportunity for effective information transmission while working at a computer or gesturing during a conversation, we decided to place supplemental notifications for the presenter in this location. Therefore, we designed our device to be as similar as possible to a conventional wristwatch. For this purpose, we 3D printed a case for the watch using PLA. Three openings were left free: a circular opening with a diameter of 37mm, providing space for all components, as well as two side-mounted slits through which the velcro strap can be threaded. The flat design of all three main components can be easily attached to the our watch case. The prototype is presented in Figure 3.2.

## 3.3 Notification Design

We used *Zoom* as the video conferencing application for our study.

For the investigation of different notification techniques on the wristband during online presentations, we decided to use *Zoom* as the base application, because it is one of the most popular and widely utilized programs for video con-

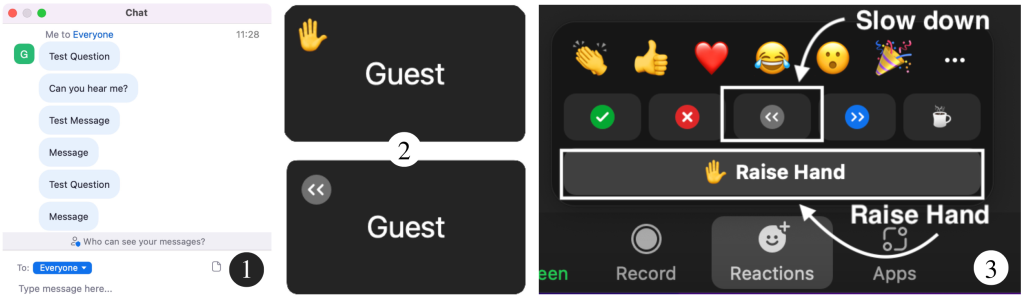


**Figure 3.4:** Zoom interaction options: (1) Chat for messages, (2) Video windows of other participants, (3) Emojis feedback.

ferencing. *Zoom* attempts to bridge the gap between traditional face-to-face meetings and digital meetings by integrating visual communication features such as text messaging in chat, video streams of attendees, raised hands, and other interaction options, as shown in Figure 3.4. However, for presenters it entails increased cognitive workload and stress, as they have to constantly monitor the screen in addition to their talk in front of the audience. To address this problem, we have designed a wrist-worn notification system for supplemental cues to support presenters. *Three semantic meanings* for notifications were selected to be studied in each modality:

1. Someone from the audience asked a question in the chat
2. One of the participants raised their hand
3. The "Slow down" emoji was sent to the presenter as a signal to reduce the speed of the speech

These three *Zoom* communication markers were individually represented in visual, haptic, and auditory modalities.

Figure 3.4 (1)-(2) demonstrates how the incoming chat messages and the emoji reactions are displayed to the users in *Zoom*. These communication markers, such as the *Chat Question*, the *Raised Hand*, and the *"Slow down"* icon, we individually represented in visual, haptic, and auditory modalities.

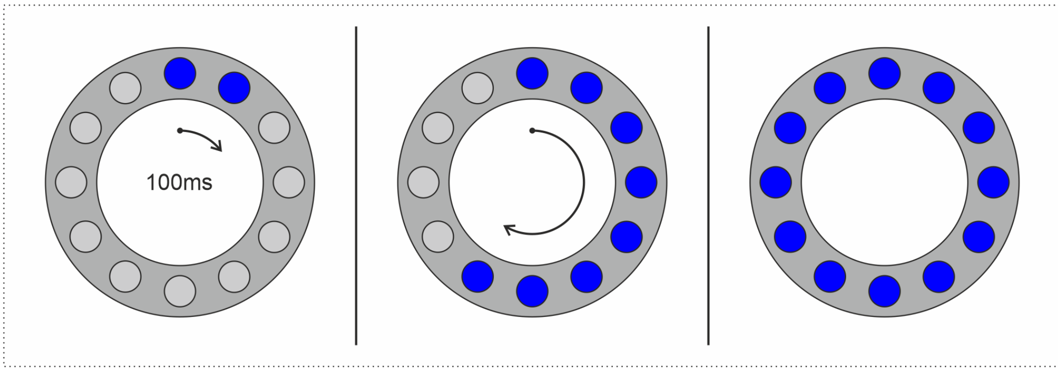


**Figure 3.5:** Illumination mode of LEDs for the visual light feedback. We used red, yellow, and blue colors for the animation pattern on the wrist-worn prototype.

When designing the feedback modes for each type of notification, we strived to make them as distinguishable from each other as possible.

With supplemental notifications on the wrist, we intended to enable presenters to be completely focused on their talk without controlling the entire screen. The user should be able to differentiate between the meaning of the various notifications. Therefore, it was necessary that the feedback modes from the wrist-worn device are distinguishable for the user.

### 3.3.1 Light Feedback

Pohl et al. [2016] inspired us to implement light animation for the LED ring.

When selecting visual feedback modes, we were inspired by Pohl et al. [2016] subtle notification mechanisms for smartwatches. The authors have investigated peripheral indirect light on a smartwatch for the transmission of notifications. For this purpose, eight red luminous LEDs were placed on the bottom of a watch case. Seven different illumination modes were implemented for the study. Three feedback modes lit up with animation patterns, while the others were static. Thus, the authors studied how well users can detect notifications presented in this way throughout the day. According to Pohl et al. [2016] results, the lighting mode does not affect the reaction time. Furthermore, the participants preferred two lighting patterns: illuminating all LEDs and illuminating LEDs with a rotating animation. Therefore, we combined these two light patterns for our visual notification feedback. The process of illuminating LEDs is shown in Figure 3.5.

When the feedback is triggered, 12 LEDs light up in succession every 100ms. After all LEDs are on, the NeoPixel ring remains lit for one second.

We decided to use different colors so that users can distinguish between the three types of notifications. The red color was assigned to the question in chat, as the messages are often associated with the traditional red popup notifications. For the raised hand emoji in Zoom, the appropriate yellow color was selected. Initially, a gray color was chosen for the "slow down" icon. However, during testing the LED illumination on two participants before the user study, we found out that the gray color was difficult to detect, so we chose the easily distinguishable blue color instead.

For each notification type, a different color has been assigned.

### 3.3.2 Vibration Patterns

For the vibration patterns, we considered the design recommendations from Graham-Knight et al. [2020]. The authors investigated how people could communicate with each other without using verbal, visual, or textual notification methods. Their main idea was to encode commonly exchanged messages between two people in a relationship with various vibrations in a subtle and non-interrupting way. Three user studies were conducted to find out which vibration properties are most appropriate for this form of communication. Graham-Knight et al. started by surveying the most common text messages in the couples' daily life. Next, they studied the smartwatch vibration properties, such as number of vibration pulses and pulse duration. Vibration patterns consisting of two, three, and four vibrations with the duration of 200, 300, and 400 milliseconds were included in the experiment. The sequence of two pulses with the equal duration (e.g. 200ms, 200ms) was afterwards excluded from the further study due to a higher error rate (20%) in determining the correct vibration pattern. Finally, the best smartwatch vibration properties were tested on users to evaluate the accuracy of detecting different vibration patterns. The vibration-to-text (blue) and vibration-to-category (green) mappings are shown in Table 3.1.

We followed Graham-Knight et al. [2020] design recommendations for the vibration patterns.

| Vibration Pattern (ms) | Text / Category |
|---|---|
| 400, 400, 400, 400 | Love you |
| 400, 200, 400, 200 | Yes |
| 200, 200, 200, 200 | Hi |
| 200, 200, 400, 400 | Good Morning |
| 200, 200, 200 | Status update |
| 400, 400, 400 | Request status update |
| 200, 200, 400 | Question |
| 400, 400, 200 | Reminder |

**Table 3.1:** Pattern-to-Text and Pattern-to-Category message mappings [Graham-Knight et al., 2020]

The findings showed that people have an ability to distinguish and interpret text messages and their related categories through trough smartwatch vibration patterns. Therefore, we have adopted the following design recommendations provided by Graham-Knight et al. [2020] for vibration-based communication:

- *"Avoid vibration duration that are too close to each other"*. We decided to choose the sequences for the vibration patterns with a clear distinction between the vibration duration of each pulse (e.g. 200ms and 400ms combinations instead of 200ms, 300ms combinations). The combinations of 100ms and 300ms were excluded from our study because the subjects on whom we tested the vibrations could barely perceive the 100ms pulses.
- *"Use a long and similar pulse duration"*. Following this guideline, the vibrations we considered for our user study contained three or four vibration pulses.

We chose a 3-pulse combination because 4-pulse vibration patterns are too distracting due to their longer duration.

According to Graham-Knight et al. [2020], a 3-pulse combination is a suitable representative for a message category and a 4-pulse for message under the category. We decided to use a 3-pulse combination because while testing both combinations on two people, we found that 4-pulse vibration patterns were too distracting due to their longer duration. Therefore, three vibration patterns with the best

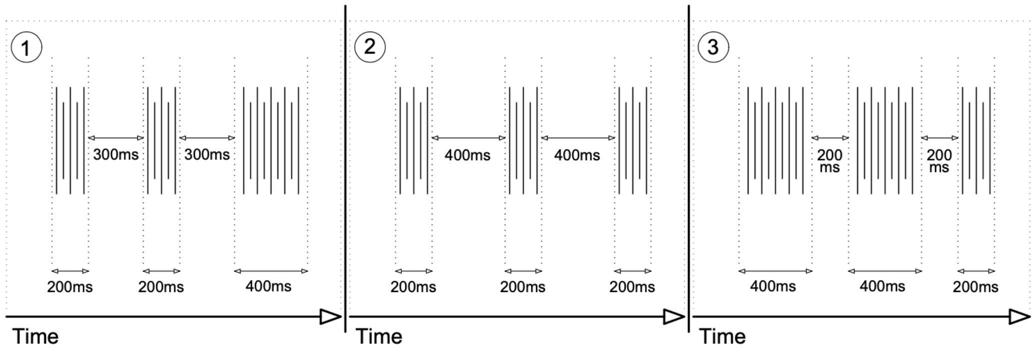


**Figure 3.6:** Vibration patterns: 3-pulse combinations with (1) 200ms-200ms-400ms pulse duration and 300ms time intervals, (2) 200ms-200ms-200ms pulse duration and 400ms time intervals, (3) 400ms-400ms-200ms pulse duration and 200ms time intervals.

accuracy from their study (94% accuracy for "Status update", 94% for "Question" and 92% for "Reminder") were adopted for our work.

To keep the duration of the vibration sequences the same, we adjusted the time intervals between two consecutive vibrations. The modified vibration patterns are depicted in Figure 3.6. As a result, the total duration of each vibration sequence lasts 1400ms.

### 3.3.3 Tone Sequences

The tone with a 800 Hz frequency and 100 ms duration was used for three tone sequences.

The auditory feedback was implemented in the form of tone sequences, with the sound similar to a traditional notification alert. Each tone at 800 Hz and a duration of 100ms was delivered through the piezo element. Similar values have also been investigated in previous research for multimodal feedback systems [Nault et al., 2020]. To prevent the tone from interrupting the presenters while speaking, the sequences were kept short and simple. We have designed the sequences of one, two, and three sound signals, where the duration of the first sequence is 100ms and of the other two sequences 500ms. The sound sequences implemented for auditory feedback are shown in Figure 3.7.

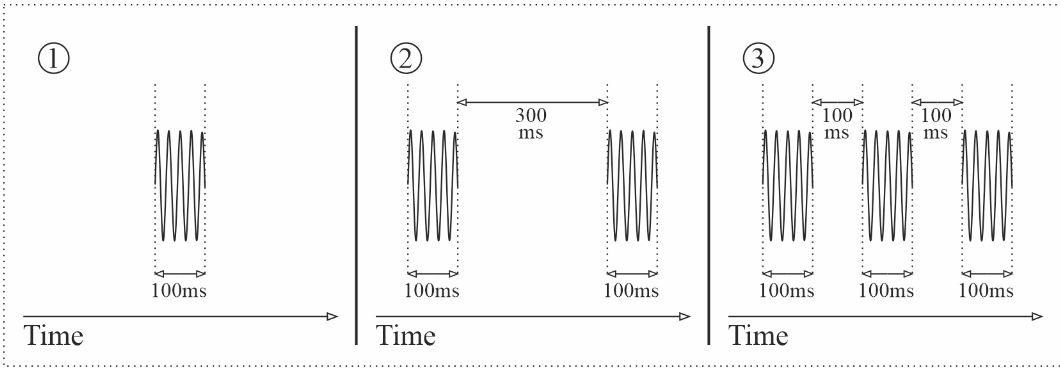


**Figure 3.7:** Tone sequences: (1) one acoustic sound for 100ms, (2) two acoustic sounds for 100ms with 300ms time intervals, (3) three acoustic sounds for 100ms with 100ms time intervals.

As a result, for each of the three types of notifications in *Zoom*, we created alternative representations in each modality on the wrist-worn device, as shown in Table 3.2.

| | LED Light color | Vibration pattern [ms] | Tone sequence [ms] |
|---|---|---|---|
| Chat question | Red | 200-200-400 | 100 |
| Raised hand | Yellow | 200-200-200 | 100-100 |
| ”Slow down” emoji | Blue | 400-400-200 | 100-100-100 |

**Table 3.2:** Overview of the wrist-worn notification to Zoom notification type mappings.

# Chapter 4

# User Study and Evaluation

In this Chapter, we evaluate different notification techniques and investigate how the presenter is impacted by the three modalities presented in the previous Chapter. Specifically, we want to compare the visual notifications already integrated into *Zoom* with the additional notifications coming from our wrist-worn prototype. Therefore, we conducted a study where the users' main task was giving a presentation to explore the use of wearable technology to deliver supplemental information during online meetings.

## 4.1 Aim

This user study explores the effectiveness, user experience, and the users' workload of four different notification modalities. Therefore, participants were asked to give four short presentations, during which they have to respond to the incoming stimuli. We aim to gather the participant's feedback in order to get an inside view on how supportive and useful these supplemental notifications on the wrist are for the presenter. Moreover, we want to find out whether participants can distinguish between three different semantics of signals presented in the same modality.

Hence, we defined the following research questions:

**Q1** How distracted were the participants during the presentations?

**Q2** How do participants perceive and interpret the various forms of feedback?

**Q3** How often do participants miss the feedback?

**Q4** Which notification technique is most preferred?

## 4.2 Hypotheses

We formulate the following hypotheses:

**H1:** Participants' reaction time with the supplemental notifications on their wrist is shorter than without.

**H2:** Participants' cognitive load with visual, auditory and vibrotactile feedback is lower than the workload without these notifications on the wrist.

**H3:** Participants can distinguish between three different semantics of signals presented in the same modality.

**H4:** With the wrist-worn device, more notifications are perceived and confirmed than in a setting without interaction with the device.

## 4.3 Independent variables

In this user study, two independent variables are defined, representing the parameters of this study:

1. **Notification modality**
   I. Three notification modalities on the wrist-worn prototype that classify the modality according to the sensory channel addressed:

   - *visual*
   - *haptic*
   - *auditory*

   II. Visual feedback modality already integrated into the video conference application *Zoom* without interacting with the wrist-worn device.

   This implies that a total of four modalities are investigated in our experiment.

2. **Number and type of notification sent to the participant**
   During each presentation, the participant receives notifications at randomized times. These notifications will appear in one of *Zoom's* forms of visual communication markers: a chat question or a raised hand or the "Slow down" emoji. For these three different signal semantics, we developed representatives for each modality on the wrist-worn device described in Sections 3.3.1-3.3.3.

## 4.4 Dependent variables

Dependent variables include several metrics that are important to determine in order to evaluate different notification modalities:

- *Accuracy*. Number of perceived and correctly confirmed notifications by pressing the buttons.
- *Reaction time*. This data is obtained by calculating the time difference between the moment the notification was presented and when the button was pressed.

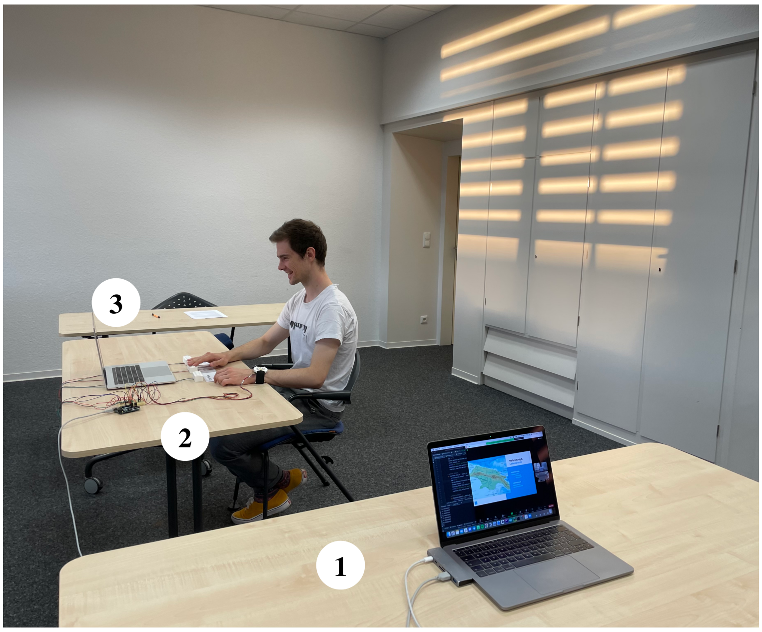


**Figure 4.1:** The setup of the study from the conductor's perspective.

- *The total workload*. The cognitive load during each presentation is measured with the National Aeronautics and Space Administration Task Load Index (NASA-TLX).

## 4.5 Apparatus

The 1st desk was used only for the study director.

Figure 4.1 gives an overview of the study setup from the conductors' point of view. Three desks were prepared for the study procedure. The 1st desk was intended for the conductor of the user study. A MacBook Pro 13-inch was placed here, which was connected to the Arduino Uno via a USB cable and from which the notifications were transmitted during the presentations.

The 2nd desk was provided for the participants during their online presentations. For this purpose, a MacBook Pro 15-inch was provided, sharing the slides in a Zoom meet-

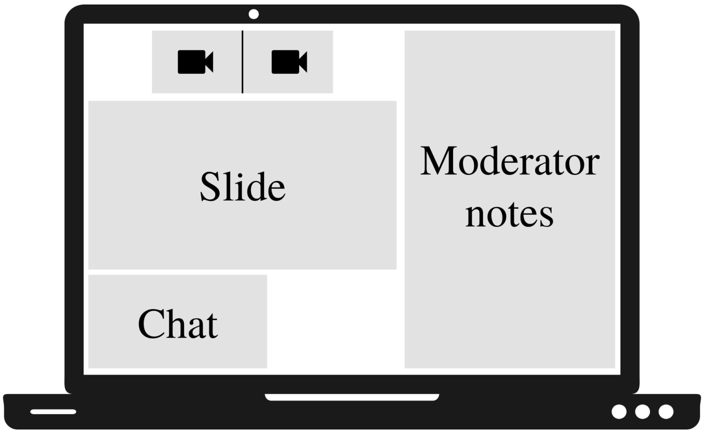


**Figure 4.2:** Screen layout during the presentation.

ing and recording the participants on a webcam. In front of the participant, three buttons were located to enable a reaction to the notification that would appear during the presentation. These buttons and the wrist-worn prototype were wired to the Arduino Uno, which was attached to the side of the 2nd desk. The Arduino location, as well as the length of the wires, were chosen to allow sufficient freedom of movement for the participants during the experiment.

The 2nd desk was provided for the participants during their online presentations.

At the 3rd desk the participants filled out the questionnaires in the periods between the presentations. During this time, the conductor prepared the setup for the next part of the study.
Since each participant has an individual presentation style and a suitable layout of the Zoom and presentation interface, a unified screen orientation was specified. Figure 4.2 illustrates the participant's display while the slides are being shared in Zoom. Keynote[1] was used as the presentation software application. The presentation mode of this program was utilized to display the supporting text next to the current slide in the "presenter's notes" window. In the top area there are the video streams of the participants. Each time a hand is raised or the "speed down" icon is sent, the corresponding emoji is displayed at the top. The same applies to the chat box - as soon as a message is transmitted in the online meeting, it appears in this window.

The 3rd desk was used for filling out the questionnaires.

A consistent screen layout was specified for the study.

[1]https://www.apple.com/keynote (*Accessed: November 7, 2022*)


**Figure 4.3:** Top view of the participant's desk. Performing the task, participants had to press the buttons when the signal was recognized.

We used pushbuttons in 3D-printed housings to measure the reaction time.

We adopted the design of Pettirsch [2022] for the buttons that are placed in front of the participants. The construction of the button includes four components. In the core is a wooden housing, to which the small DTS61K button is attached. To enlarge the touch surface, a PLA cuboid was 3D printed and placed above the electronic button. An additional PLA frame holds the whole construction in position. We have adjusted the height of this outer framing for more stability when pushing the button. The buttons described above that were used for the experiment can be seen in Figure 4.3.

The experimental software was developed in C++ using the Arduino IDE and run on a MacBook Pro 13-inch. It involved sending different types of notifications to the wrist-worn prototype for execution and tracking the button presses of the users. Recorded measurement data was stored in TXT files for further evaluation.

## 4.6 Design and Task

For our experiment, we asked the participants to complete two kinds of tasks: (1) giving a presentation (a typical task in online meetings) and (2) a secondary task requiring the participants to respond to incoming notifications by tapping the right button in parallel with the main task being performed.

Participants had to give presentations and respond to incoming signals by pressing the buttons.

### 4.6.1 The Primary Task

In the context of online meetings, it is essential to consider the fact that the participant should be in an environment that is appropriate to the atmosphere of the presentation. Therefore, we asked the participants to give a presentation using the *Zoom* video conferencing tool.

Since the wrist-worn device has three feedback modalities: visual, auditory, haptic, which we compare to the visual modality with the notifications already integrated in Zoom, four presentations are required for the study. While the participant is giving a presentation, only one modality is tested. Participants were instructed to prepare and give four talks on pre-selected topics. The topics were chosen to ensure that the content of the presentation has an appropriate level of difficulty. We selected four extraordinary animals: "Ailuridae", "Tarsier", "Birds-of-paradise" and "Axolotl". To facilitate the preparation of the presentations, we provided templates with eight to nine slides on interesting and key facts of the animals. We wanted to keep the presentations as similar as possible, so that the modalities have the same preconditions. Therefore each presentation has a similar structure and consists of about 1200 words. This corresponds to approximately seven minutes of speaking time.

We have prepared presentation templates to facilitate preparation for the talks.

### 4.6.2 The Secondary Task

For the secondary task, participants had to press a button when they received an incoming notification. Here, the type of a notification informs participants which of the three buttons should be pressed. Each button corresponds to the meaning of the notification received and is labeled with the text, as shown in Figure 4.3.

Each button was text labeled with the corresponding meaning.

The idea, to add supporting text labels, comes from the research work we mentioned previously in Section 3.3.2. Graham-Knight et al. [2020], in their study exploring different vibration pulses, provided users with a paper in which each vibration pattern was labeled with the corresponding meaning. It helped the participants to strengthen their spatial memory for matching the vibrations to the correct categories.

Participants received six notifications during each presentation - two notifications per notification type.

During each presentation, Zoom-integrated visual communication markers were sent to the participants: a question in the chat window, a raised hand, or a "Slow down" symbol. All Zoom notifications were manually triggered by the user study conductor. Participants received *six* notifications during each presentation, with two notifications from each of the three types of signals. Notifications from the wrist-worn prototype were received when additional feedback from the wearable device was being tested, i.e., during three of the four presentations.

The signals from the wrist-worn prototype and Zoom's visual notifications were synchronized.

The wrist-worn signals had to be synchronized with the Zoom notifications. For this purpose, we have developed a help program in Python in order to automatically send the stimuli to users at predefined times. Therefore, each time the conductor manually sends a Zoom notification, a notification is also delivered to the wrist-worn device.

## 4.7 Experimental Design

We conducted a pilot study with one user before beginning the study process. First, we wanted to make sure that the design was complete, and to identify any missing points. Second, to determine how long the study would take per participant. As a result, we have found that the experiment will take approximately 90 min.

Since participants had to compare the different notification modalities, we used a within-subjects study design. We counterbalanced the notification modalities using a Latin square, shown in Table 4.1. In the following, the *visual* modality of the wrist-worn prototype is defined as LED, the *vibrotactile* as Vibration and the *auditory* as Sound. The modality without additional notifications, i.e. only the visual feedback already integrated in *Zoom*, is referred to as Baseline.

Furthermore, we randomized the sequence of presentations by which the participant performs and the order of the types of notifications to prevent possible learning effects during the experiment. In a real online meeting, messages can be sent at any time. Therefore, we also randomized the time points at which the stimuli were triggered over the presentation length.

| | | | |
|---|---|---|---|
| LED | Vibration | Sound | Baseline |
| Vibration | Baseline | LED | Sound |
| Baseline | Sound | Vibration | LED |
| Sound | LED | Baseline | Vibration |

**Table 4.1:** Balanced Latin Square for determining the order of the modalities for each participant.

Our approach tested four notification modalities, resulting a within-subjects model with: 4 *Notification Modalities* $\times$ (3 *Notification Types* $\times$ 2 Repetitions of each *Notification Type*) = 24 data points per participant.

## 4.8 Participants

Since we are in the context of online presentations, we only recruited participants who has ever used video conference applications such as Zoom, Microsoft Teams, Skype, etc., and anyone with at least some experience with public speaking.

We recruited 16 participants for our user study.

Sixteen people participated in our study. Their age ranged from 21 to 30 (M = 24.56, SD = 2.98). Eight participants were male, seven were female, and one participant was non-binary. One participant reported being left-handed. All participants had a scientific background and experience with public speaking in online meetings.

## 4.9 Study Procedure

A list of randomized time points for the stimuli was generated for each study.

Before each study, a list of randomized time points and order of notifications was prepared and entered into a Python program, automatically triggering the stimuli during presentations. The interval between two stimuli was defined as at least 10 seconds to give the conductor enough time to prepare to send the next cue in Zoom.

At the beginning of the user study, participants were asked to read the consent form (Appendix A.1). Afterward, participants had to take a seat at a desk where presentations and interaction with the device were conducted. Participants were informed about the experiment and the structure of the study, which was divided into four parts, each of which tested one feedback modality. For each participant, a new Zoom meeting was started. The meeting had no real audience, only the study conductor and the participant themselves were members of the video conference. Participants were asked to wear a prototype on their non-dominant hand during each presentation, even when no notifications were transmitted to the bracelet. Before each talk, the concept of notification modality and interaction with the buttons when receiving signals were explained to the participants. Additionally, participants had an op-

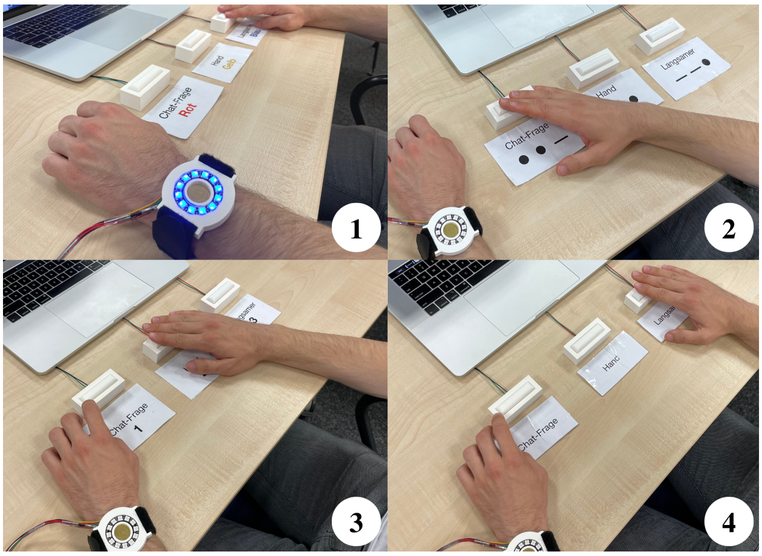


**Figure 4.4:** (1) The LEDs light up blue and the participant confirms the signal by pressing the button. (2) Vibration patterns were represented by dots and dashes; a dot stands for a short vibration, a dash - long vibration. The participant assigns the incoming message to the chat question. (3) The participant hears a sequence of two tones and presses the 2nd button. (4) The participant notices a "Slow down" emoji during the presentation, without having supplemental notifications on the wrist.

portunity to familiarize themselves with each signal type by pressing the matching button. This phase lasted until participants were confident in recognizing every stimulus. Next, participants prepared for the presentation, for which approximately five minutes were given. After the timer expired, participants were asked to start their talk.

Overall, six notifications were triggered during each five-minute presentation. We have purposely prepared presentations and text for each slide with a longer duration (approximately seven minutes), as all speakers present at their own appropriate pace. During this time, the conductor manually sent notifications via the Zoom application interface in accordance with a previously generated time-code protocol. Figure 4.4 demonstrates the process of notification confirmation by the participant in each modality.

After each presentation, the wristband was taken off and participants were asked to fill out a questionnaire to evaluate their experience with the notification technique (Appendix A.3). During this time, the study conductor prepared the next phase of the experiment, uploading the following program to the microcontroller and changing the presentation slides and the text labels in front of the buttons.

Once participants had given all four presentations, they were asked to complete a final questionnaire asking them to provide personal demographic information and their ranking on all four notification techniques (Appendix A.6). Finally, we conducted a short semi-structured interview focusing on the participants' experience during the task.

## 4.10 Measures

We measured reaction time, error rate, task load, user experience.

We used several measures to compare four different modalities with each other. We measured the reaction time in the secondary task by calculating a time difference between the moment when the stimuli were triggered and when the user pressed the button. The system also registered whether the type of notification was correctly detected. Moreover, we evaluated perceived cognitive load while completing the task utilizing NASA Task Load Index. NASA-TLX is the most widely accepted assessment tool for measuring workload after task completion [Said et al., 2020]. For our case, we used the *"Raw"* NASA TLX, which eliminates the weighting process. This variation can be completed more quickly because only six scale values need to be entered by participants. Additionally, we assessed the usability of the wrist-worn device with the short version of User Experience Questionnaire (UEQ-S). Since we consider four modalities that were examined in close succession during the study and the complete UEQ consists of 26 questions, we decided to use the UEQ-S. Otherwise, participants would be stressed by the number of questions.

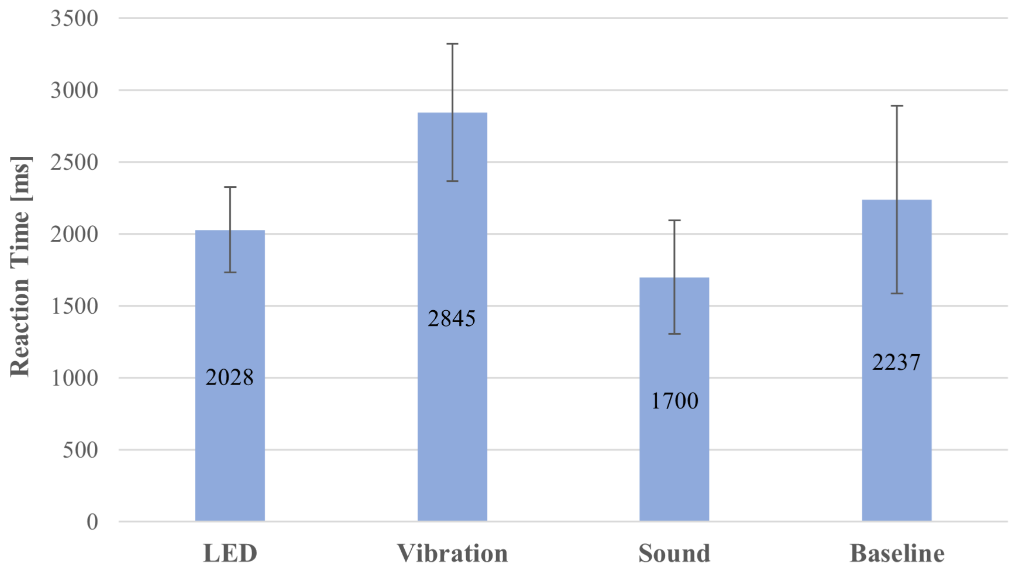


**Figure 4.5:** Means and standard deviations of reaction time [ms] regarding how fast participants reacted to incoming notifications during presentations.

In addition to quantitative feedback, we also asked participants to provide their qualitative feedback after each presentation. We wanted to assess the participant's perception of the notifications in the presented modality. Participants reported their agreement on a 5-point Likert scale for each question. Furthermore, the questionnaires included several free text fields, where the participants could leave their comments and improvement suggestions.

We gathered qualitative feedback through the 5-Likert scale with questions regarding each notification modality and free text fields for comments.

## 4.11 Results

### 4.11.1 Reaction Time

Firstly, we analyzed the reaction time of the four different notification techniques. The means and standard deviations of the investigated modalities are illustrated in Figure 4.5. In calculating the average reaction time, correct and incorrect confirmations were considered. It can be seen that the auditory modality has the shortest reaction time

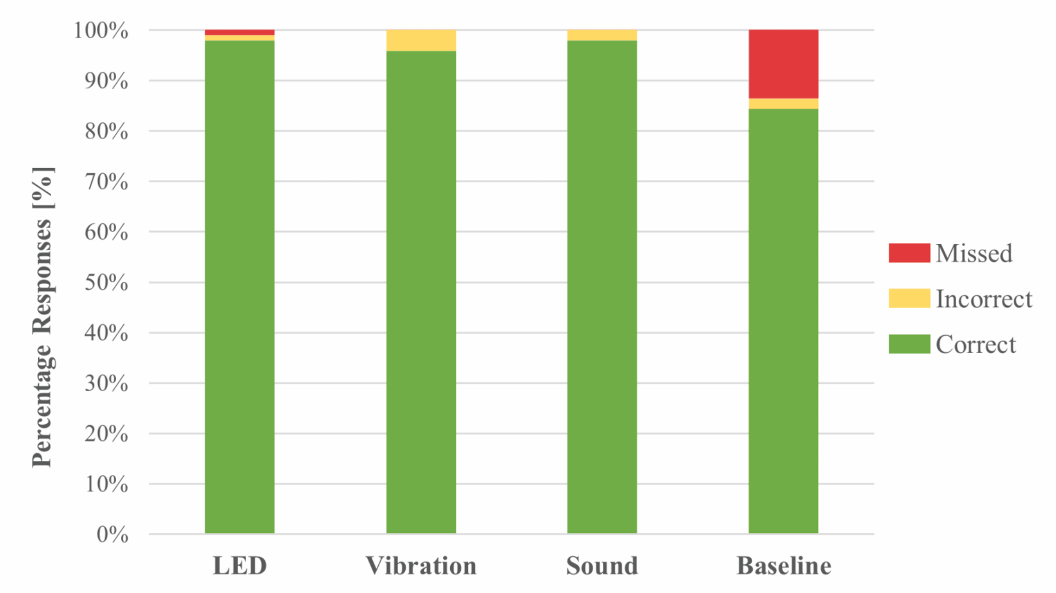


**Figure 4.6:** Percentage of correct, incorrect, and missed responses during the primary task by modality.

The auditory modality resulted in the shortest reaction time.

compared to all other modalities. In contrast to the Sound, participants took the longest to respond to vibration stimuli. However, it should be noted that during the secondary task, namely mapping the signal to one of the buttons, most participants waited until the end of the vibration sequences (each of three vibration patterns lasting 1400ms) and only then confirmed the perceived notification. This was performed on average faster with the LED illuminations than with the vibration stimuli. Since the duration of the light illumination is 2200 ms, it can be observed that participants could detect the emitted light and press a button 200 ms before all the LEDs were switched off. From the bar chart, it is clear that the modalities on the wrist, except the Vibration, achieved a shorter reaction time than the Baseline without the supplemental notifications.

### 4.11.2 Error Rate and Accuracy

The stacked bar chart in Figure 4.6 provides information about the number of correct responses. As can be seen, the visual, vibrotactile, and auditory modalities achieved

a high rate of correct signal recognition with 98%, 96%, and 98%, respectively. Without supplemental notifications on the wrist-worn prototype, the error rate in our study of the Baseline is 16%. 75% of the participants missed at least one notification without additional wrist-worn signals.
With the support of auditory and vibrotactile feedback, no stimuli were missed by participants. However, slightly more errors were detected in Vibration than in any other modality.

The wrist-worn modalities achieved a higher rate of confirmed signals than the Baseline.

### 4.11.3 NASA Task Load Index

As mentioned earlier, the cognitive load during the primary and secondary tasks was measured by using the NASA-TLX. The workload index consists of six categories, each of which is scored on a 100-point scale in 5-point increments, whereby lower ratings equal better results. These are *Mental*, *Physical* and *Temporal Demand*, the estimated *Performance*, *Effort*, and *Frustration*. A detailed description of each category is displayed in the questionnaire attached in Appendix A.3. The index is calculated as the mean of all categories as well as individually for every category.

From Table 4.2, it can be observed that the Sound has the lowest averaged cognitive load followed by LED. In contrast, the Baseline achieved the highest workload during the primary and secondary tasks.

| Overall Rating | LED | Vibration | Sound | Baseline |
|---|---|---|---|---|
| Mean | 28.70 | 44.58 | 22.40 | 48.23 |
| SD | 20.12 | 26.05 | 16.80 | 22.63 |

**Table 4.2:** Means and standard deviations of the overall "Raw" NASA-TLX rating for each sensory notification modality.

Figure 4.7 shows four of the six categories we are especially interested in. It can be seen that information processing was lowest for the Sound (Fig. 4.7 *Mental Demand*). On the other hand, Vibration and Baseline required a high concentration

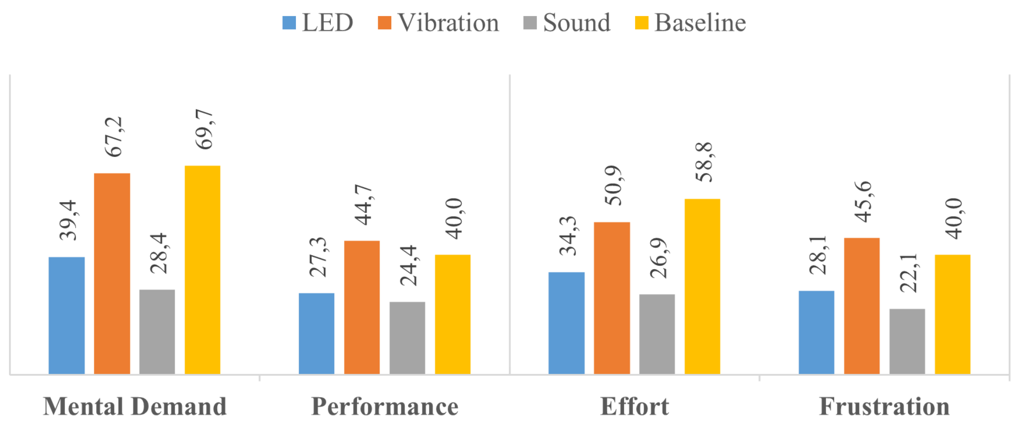


**Figure 4.7:** "Raw" NASA TLX Results in four categories: *Mental Demand*, *Performance*, *Effort*, *Frustration*. Participants rated the scales numerically from 0 (low - good) to 100 (high - bad).

level and were demanding in performing the task (Fig. 4.7 *Mental Demand*).

Based on NASA TLX, the visual and auditory modalities scored the lowest (best) workload.

Based on the participants' feedback, they were more successful when giving presentations and responding in parallel to incoming notifications using the visual and auditory notification modalities of the wrist-worn device (Fig. 4.7 *Performance*). A relatively high level of *Effort* was observed for the Baseline and the Vibration. In addition, both with vibration cues and without supplemental notifications on the wrist, participants were more likely to feel insecure, stressed, and annoyed (Fig. 4.7 *Frustration*). Overall, we can observe that Sound and LED did not produce a high overall workload across these NASA-TLX subscales compared to Vibration and Baseline.

### 4.11.4 User Experience Questionnaire - Short

Unlike the full UEQ, which measures six different dimensions that subsequently define the user experience score, the short version measures only two dimensions: *Pragmatic Quality* and *Hedonic Quality*. Each dimension contains four items, i.e., four opposite pairs of adjectives. Therefore, the overall UEQ-S score consists of eight items.

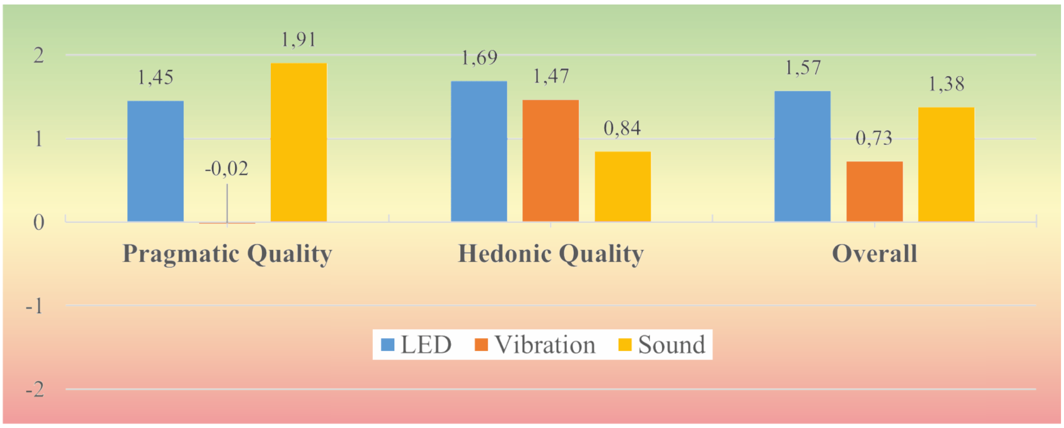


**Figure 4.8:** UEQ-S results of the notification modalities of the wrist-worn prototype. Values $< -0.8$ indicate a negative score and values $> 0.8$ - a positive score.

The *Pragmatic* aspects of quality determine how useful the product is for efficiently performing a task and the ease of interacting with the product. *Hedonic* quality aspects are responsible for the joy and emotions caused by using the product. During the study, participants had to decide for a tendency in each word pair on a 7-point Likert scale. We wanted to analyze the use of the device during the presentation, so we applied the UEQ-S only to the modalities on the wrist. Figure 4.8 illustrated the UEQ-S results for visual, vibrotactile and auditory modalities. According to the UEQ-S, values higher than 0.8 are considered positive and values lower than -0.8 indicate a negative evaluation. Values between -0.8 and 0.8 correspond to a neutral evaluation.

LED demonstrated the best *Overall* results, Sound - the highest *Pragmatic* quality, and Vibration the lowest *Pragmatic* quality.

It can be observed that LED was the only modality that yielded a positive result in *Pragmatic* quality as well as in *Hedonic* quality and demonstrated the best overall result compared to the other modalities. Sound achieved the highest *Pragmatic* quality but, in contrast, the lowest score for *Hedonic* quality. The only modality that scored rather negatively in the *Pragmatic* measurements was vibration. But regarding the overall result, vibration was assessed as neutral due to its high *Hedonic* quality.

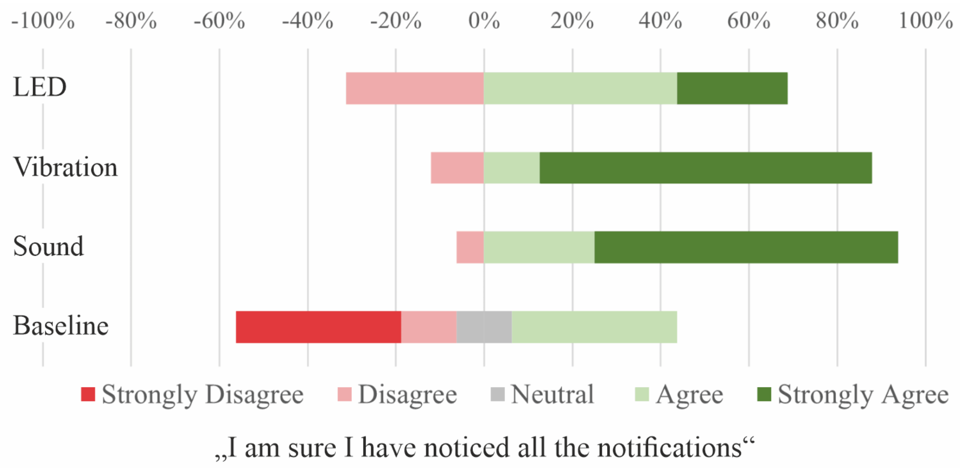


**Figure 4.9:** Evaluation of the first statement from the Likert scale.

### 4.11.5 Likert Scale

After each presentation, participants were also asked to provide their feedback on the notification techniques. We formulated several statements on which each participant had to indicate their level of agreement on a 5-point Likert scale.

50% were unsure if they noticed all incoming notifications on the screen without supplemental notifications.

In Figure 4.9, it can be seen that the participants felt more secure in detecting the notifications with the help of the wrist-worn prototype than without it. Concerning the Baseline, half of the participants were unsure whether they noticed all the incoming notifications on the screen or not. About 30% of the respondents also felt rather unsure about the perceived number of signals via the LED ring.

We also asked study participants if they were distracted by notifications. The bar graph compares the answers obtained in all four modalities (Fig. 4.10). 82% of participants stated they were distracted during the presentation without receiving supplemental notifications because they often had to control the entire monitor display fearing to miss a notification. At the same time, about 70% of the participants were not interrupted from the presentation while receiving sound cues. LED demonstrated better results than Vibration. For more than half of the participants, feedback in the form of vibration signals seemed distracting during the primary task.

Without additional feedback, participants were most distracted during the presentations.

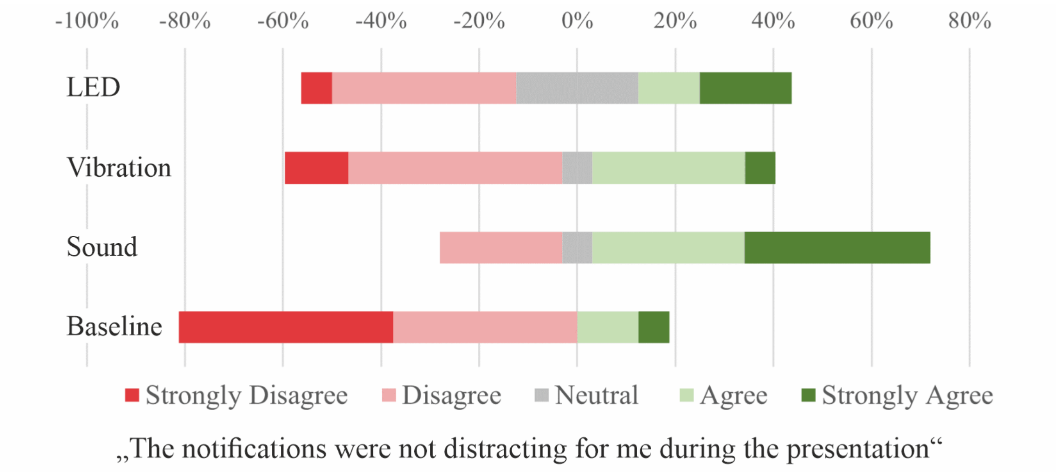


**Figure 4.10:** Evaluation of the second statement from the Likert scale.

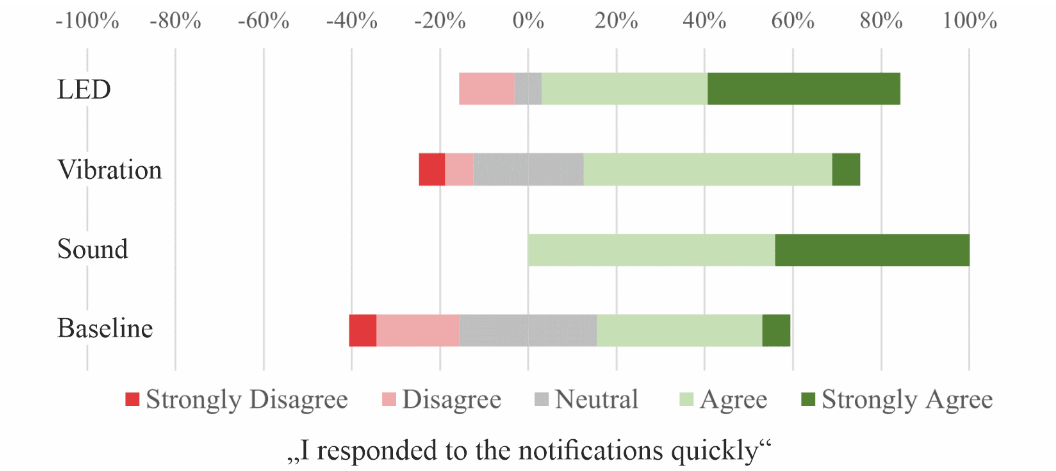


**Figure 4.11:** Evaluation of the third statement from the Likert scale.

All participants reported they quickly responded to the notifications using the auditory modality.

Figure 4.11 shows that while using the wrist-worn device, participants tended to feel they responded quickly to the incoming information. All participants indicated that they reacted rapidly to audio cues during the primary task. Some participants believed that their response was not especially fast when only the visual feedback modality integrated in Zoom was used.
Additionally, we wanted to discover whether participants could distinguish between three different semantics of signals presented in the same modality, so we were interested in two related questions.

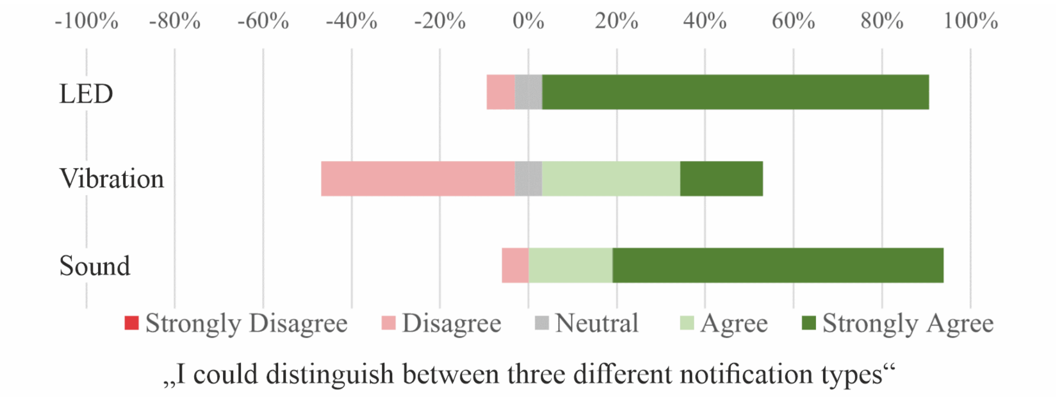


**Figure 4.12:** Evaluation of the fourth statement from the Likert scale.

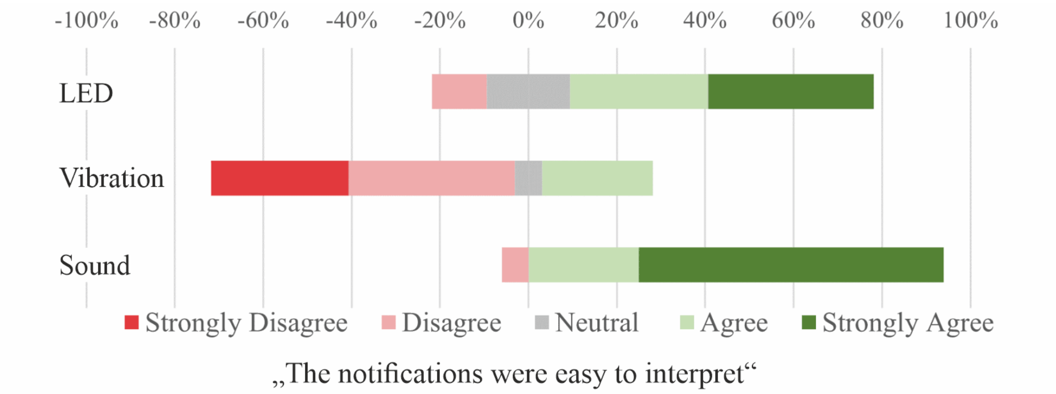


**Figure 4.13:** Evaluation of the fifth statement from the Likert scale.

All except one participant could differentiate the tone sequences, and 88% could differentiate the colors of the LED light coming from the wrist device, as shown in Figure 4.12. However, for half of the participants, the chosen vibration patterns for haptic feedback proved challenging to distinguish.

The vibration patterns were not particularly distinguishable and difficult to interpret.

A similar trend can be observed in Figure 4.13. Almost all participants could easily interpret the received signal in the visual and auditory modalities. Compared to the LED and Sound, it was difficult for 69% of the participants to match the vibration pulses to the correct type of Zoom notifications.

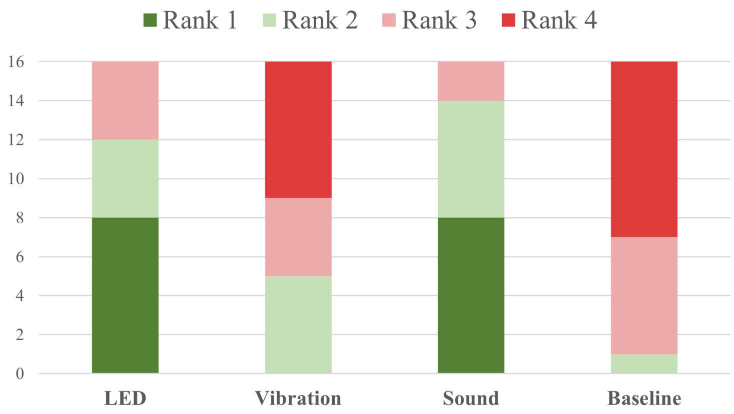


**Figure 4.14:** Ranking of the modalities. Ranks 1 to 4 could only be assigned once, whereby 1 is the best and 4 is the worst.

### 4.11.6 Ranking of the Modalities

The rankings of the notification modalities can be observed in Figure 4.14. Baseline and Vibration were generally ranked significantly worse than Sound and LED. Nine out of 16 participants rated Baseline, the modality without supplemental notifications, as the worst notification modality. In contrast, five participants placed Vibration in second place. LED and Sound were never ranked as the worst notification technique while presenting. In addition, the chart illustrates that Sound and LED were equally ranked first by the participants. Furthermore, participants evenly often assigned second and third place to LED. In contrast to LED, Sound was slightly more often ranked second. As a result, this type of feedback was ranked last by more than half of the participants.

Sound and LED were equally ranked best.

## 4.12 Participant Remarks

After each presentation, participants could leave comments on what they liked or did not like about their experience with different feedback types and suggestions for improvements in each modality. In the following, we will briefly summarize the most common feedback from the participants. Since we conducted the study in German, the respondents' comments were translated into English.

The LED light was perceived by several participants in the periphery.

Regarding the visual notification modality of the wrist-device, six of the 16 participants remarked the **LED illuminations** could already be noticed at the periphery of vision:

*"LEDs were bright so you could see them without having to look at them. They helped me to focus only on slides / text and not on the zoom features."* (P8)

*"It was very easy to distinguish the types of alerts from each other. The colors were bright and easy to notice with the peripheral vision."* (P15)

Some participants were not satisfied with the positioning of the light illumination.

However, several participants did not appreciate the positioning of the LEDs for notifications during the online presentation:

*"When you are constantly looking at the screen, it is difficult to pay attention to the wristband."* (P10)

*"I didn't like the location on my wrist because the light was away from my body."* (P7)

Consequently, seven participants suggested placing a visual form of supplemental feedback for the presenter in a different location: *"closer to the screen"* (P16), *"behind the screen"* (P10), *"at the top or bottom of the screen"* (P12).

The vibration patterns were too complex for most.

The **vibration patterns** were often criticized by participants for their complexity, hence it was difficult to interpret the vibration sequences:

*"It was very difficult to keep in mind the meaning of each pattern [...] If there had been a distinction based on the number of pulses (1,2,3), I would have given 2nd place."* (P12)

*"For me, the vibration was just a hint to check the communication areas without really paying attention to the vibration pattern."* (P6)

Vibration was always perceived, leading to the safe feeling of not being afraid of missing the messages.

On the other hand, it was reported that the vibration provides a safe feeling that the messages are not missed.

*"I wasn't afraid to miss any important information."* (P2)

*"The vibration is hard to miss, because it is always possible to notice when an alert has appeared."* (P14)

Many participants appreciated the ease of interacting with the **auditory feedback**:

The auditory modality received positive feedback due to its simple sound patterns.

*"It is not distracting, easily distinguishable, and does not require much mental capacity for interpretation."* (P1)

*"Easy to understand, acoustic signals are common in everyday life."* (P4)

Moreover, it was often reported that they could concentrate on the presentation using a different feedback modality to perceive the incoming messages:

One participant reported it is easier to concentrate on the presentation using a different modality.

*"The notification technique did not distract from the talk and still made it possible to notice all the notifications. On the screen, I would have missed the notifications. It's good to use a different modality."* (P12)

At the same time, several participants mentioned the potential annoyance caused by sounds if they constantly appear during online meetings:

The sounds could be annoying if they would constantly come up.

*"Conspicuous in official presentations → annoying for the audience?"* (P3)

*"During the presentation someone may hear signals on the other side."* (P10)

Concerning the visual modality already integrated in **Zoom,** 11 participants reported a heavy visual load and constant monitoring for alerts:

It was challenging for the participants to monitor the messages constantly without additional help.

*"I had to repeatedly look at the chat / video window or even at the entire display [...] I couldn't pay full attention to the talk."* (P2)

*"I'm sure I missed some notifications and it was complicated to keep track of all the notifications."* (P15)

## 4.13 Discussion

The modalities of the wrist-worn device mostly achieved better results than the Baseline without supplemental notifications.

Based on the evaluated data, it can be observed that the modalities of the wrist-worn device mostly achieved better results. Our evaluation confirms **H4** that participants missed more stimuli *without supplemental wrist notifications*. Concerning the Baseline, the interesting finding is that even though the rate of missed notifications is only 14%, half of the participants were still unsure whether they perceived all the incoming signals, as shown in Figure 4.9. As mentioned earlier, a lot of participants expressed concern by constantly checking the display, fearing to miss important information. Consequently, the Baseline achieved the highest, thus most demanding, overall workload score, as shown in Table 4.2 and required a high level of information processing compared to other modalities (Fig. 4.7). Therefore, we confirm **H2** and believe this is why more than half of the participants ranked this feedback last.

The complexity of the vibrotactile patterns affected the lower results on several measures of vibrotactile modality.

Previous research has found that the *vibrotactile* modality is a viable candidate for providing communication cues to the speaker during a presentation as additional support [Tam et al., 2013, Damian and André, 2016]. However, in our study Vibration proved to be mentally demanding. This can be explained by the complexity of the vibration patterns we have chosen, which also led to the longest response time. Participants needed more time and concentration to correlate the vibration sequence to the correct type of notification. Therefore, we cannot completely confirm **H3**. In addition, Vibration had a lower *Pragmatic* quality, indicating a lack of usefulness of this notification modality for efficient task performance. The results are also supported by participants noting that the vibration cues were challenging to interpret and distracting for most, as depicted in Figures 4.10, 4.13. However, we found that participants were able to process the received vibration stimuli under a high workload. This is evidenced by the number of confirmed vibrations and the obtained feedback from participants that haptic modality provides a safe feeling that messages are not being missed. Therefore, we still believe there are suitable vibration patterns for supporting presenters in online meetings in a non-distracting way. Nevertheless, the vibrotactile modality must be kept as simple as possible to reduce the amount of processing information. Vibration patterns need to be further explored in future research, particularly whether *Pragmatic* quality of this feedback type could be improved if users were more practiced in its use.

Auditory and visual modality are ranked first and second, respectively, in various evaluation diagrams.

When evaluating the study results of the *auditory* and *visual* modalities of the wrist-worn device, clear tendencies can be identified for several measurements. First, it is noteworthy that these two modalities are ranked first and second in various evaluation diagrams. In the following, starting with the reaction time, these will be explained in more detail. **H1**, apart from vibration due to its complexity, is supported by the fact that the reaction times of Sound with 1700ms and LED with 2028ms are the shortest of the compared notification techniques. The trend that Sound performs slightly but noticeably better also continues in the diagram with the percentage of correct, incorrect and missing reactions (Fig. 4.6). Both achieved the highest number of correct responses. A problem during the study that we had not considered when developing the prototype is that the piezoelectric element, which was attached with the golden side up, was reflecting light from the ceiling lamp in the experimental room. As a consequence, a few participants during the presentations had the feeling that a light illumination was appearing in their field of vision. Moreover, the results show the similarities in terms of cognitive load, as shown in Figure 4.7. Despite their common tendencies in this respect, there is a significant difference between them regarding mental demand. This implies the task with the visual cues emitted from the wrist was more challenging for the participants and required a higher level of awareness. It can be explained by the previous research in that it is easier for the user to attend to another sensory channel that is not involved in the primary task [Damian and André, 2016, Freeman et al., 2017]. Another indication of higher information processing during the presentations is that several participants often looked at the wrist-worn device while receiving light illuminations from it, as depicted in Appendix B.1. We believe that for this reason, 44% of the participants were distracted by the supplemental LED notifications (Fig. 4.10). We observed a correlation between task load and participants' ranking. The higher the cognitive load of the modality was, the lower the ranking it received. Since the difference between the workload of LED and Sound was rather insignificant and overall lower in comparison to the other modalities, they were equally ranked best.

Participants described the auditory modality as boring rather than exciting and as conventional rather than innovative.

Regarding *Hedonic* quality, it needs to be mentioned the good performance of the Vibration (1.47) especially compared to the results of the Sound (0.84), only surpassed by the values of the LED (1.69). Participants were likely to describe the auditory modality of the wrist device as boring rather than it was an exciting experience to them. This is matched by the description of the modality as conventional, i.e. already known and not particularly innovative.

The results show that providing supplemental feedback conveyed differently from traditional on-screen communication indicators, as in our case with the wrist-worn device, can be helpful for presenters in online meetings. This would provide more opportunity for speakers to focus on their slides and at the same time not be afraid to miss important information.

Providing supplemental feedback that is different from the traditional on-screen indicators can be helpful for online presenters.

The results obtained for the auditory modality indicate the effectiveness of using the channels differentiated from the occupied sensory channel during the primary task.

However, based on the feedback we received from participants and the high hedonic quality score, the use of LED illumination in the near periphery might be a viable option for informing users of incoming signals. Many participants expressed a desire for a different location for the LEDs. It was often remarked that placing visual notifications close to the screen, but still in the field of view, could serve as a more unobtrusive option for transmitting feedback. In addition, a few participants appreciated the idea of using light animations to attract attention.

Vibration on the body guarantees that notifications will be perceived. Because the vibration cues we designed were difficult to interpret, many participants suggested using vibration exclusively to indicate the appearance of a message without using complex patterns. Several participants expressed the idea of using vibration to highlight an incoming notification and the color of the light illumination to represent the actual meaning of the received information.

# Chapter 5

# Summary and Future Work

## 5.1 Summary and Contributions

In this work, we investigated different modalities to support presenters in online meetings via a wrist-worn device. We aimed to understand the impact of supplemental notifications on visual attention and workload to enable presenters to be focused entirely on their talk without constantly checking for incoming feedback from the audience.

We explored modalities to understand the impact of notifications on the presenter.

For this, we designed a prototype to explore the use of wearable technology during online meetings. We then conducted a user study to compare the visual notifications already integrated into Zoom with the visual, auditory, and vibrotactile notifications coming from our wrist-worn device. Therefore, participants were asked to give four short presentations, during which they had to respond to the incoming stimuli. We evaluated the effectiveness, user experience and the workload of four different notification modalities.

A prototype was developed for evaluating the wrist-worn modalities with the visual modality in Zoom.

According to the results, the use of multimodal notifications could lead to a deeper focus on the primary task by efficiently allocating users' attention. Almost every partici-

Multimodal feedback leads to better concentration during video conferences.

pant stated being overwhelmed and frustrated without the additional help of the device. One participant noted *"It was confusing and demanding to be aware of everything"*. For this reason, multimodal feedback needs to be integrated while video conferencing, but it should also be intuitive and clear in its interpretation.

The visual modality in the form of light illumination and the auditory modality both received a positive rating from the participants. The vibrotactile modality was less preferred due to the complexity of the vibration patterns.

From the feedback of the participants, they were more successful in giving presentations and responding in parallel to incoming notifications using the *visual* and *auditory* notification modalities of the wrist-worn device. These types of feedback did not cause high cognitive load relying on NASA-TLX compared to the *vibrotactile* modality and visual feedback modality already integrated into *Zoom*. The lowest response time and highest ranking of auditory modality indicate the effectiveness of using channels different from the occupied sensory channel during the primary task. However, utilizing light in the near periphery to inform users of incoming signals could be also a viable solution. The vibration patterns were not effective enough for receiving the user about the feedback from the audience. In our study, the vibrotactile modality required a high level of information processing by the users. This can be explained by the complexity of the vibration pulses we developed. Nonetheless, vibration provides assurance that messages will not be missed.

## 5.2 Future Work

Future research is required to investigate further effective notification techniques for online meetings.

The use of videoconferencing platforms is expected to remain in the post-pandemic environment. According to Lee et al. [2022], "users have high expectations and demands for technologies and designs that current video conferencing tools do not support". This indicates a further need to investigate the possible effective methods for delivering information during online meetings in order to improve the user experience.

Despite some negative aspects of the vibrotactile modality in our analysis, vibration patterns transmitting direct signals through the body provide confidence in knowing that notifications will not be missed. Accordingly, further research could be done to find optimal, suitable vibration patterns to support speakers without interfering with their attention. Nevertheless, the design must remain simple to reduce the amount of information processed.

Because the vibration design we developed was difficult to interpret, it was suggested to use vibration exclusively to indicate the appearance of a message. Therefore, we recommend considering a combination of light illumination and vibration when further exploring the types of feedback for presenters. The color of the light illumination may serve to represent the actual meaning of the received information. This is supported by the results of our study that participants could easily recognize the colors and assign them to their respective meanings.

Furthermore, future research may consider including the different placements of visual notifications in the near periphery of human vision as an independent variable when examining the impact of notifications in videoconferencing conditions.

Upcoming research could focus on enhancing enjoyment with auditory notifications and making the representation of information received more innovative, for example, using auditory icons or other tones with varying pitches instead of using traditional conventional sounds.

# Appendix A

# User Study Questionnaires

## Einverständniserklärung

**Studientitel:** Investigating Modalities for Supplemental Notifications in Online Presentations via a Wrist-Worn Device (Untersuchung von Modalitäten für zusätzliche Benachrichtigungen in Online-Präsentationen über ein am Handgelenk getragenes Gerät)

**Studienleiterin:** Ulyana Lavnikevich

**Beschreibung:** Sie sind eingeladen worden, um an einer Forschungsstudie teilzunehmen, welche sich mit den Benachrichtigungen in Online-Meetings beschäftigt. Dabei wird die Verwendung eines Armbands zur Übermittlung zusätzlicher Benachrichtigungen während des Vortrages untersucht.
Während der Studie werden Sie insgesamt vier kurze Präsentationen halten und parallel auf eingehende Mitteilungen reagieren. Es werden die bereits integrierten visuellen Benachrichtigungen der Videokonferenzanwendung Zoom mit den vom Armband ausgehenden Signalen verglichen. Durch das Armband werden Licht-, Audio- und Vibrationssignale übermittelt. In jeder Präsentation wird nur eine Benachrichtigungsart verwendet.
Für jede Präsentation werden Sie etwas Zeit haben, um sich mit den vorgegebenen Folien vertraut zu machen und den Vortrag vorzubereiten. Vor Ihnen werden sich drei beschriftete Tasten befinden. Sie werden auf eine bestimmte Taste drücken, wenn Sie eine Benachrichtigung bemerkt und erkannt haben. Sie werden die Möglichkeit haben das Armband und die Bestätigung eingehender Signale mehrmals zu testen.
Während der Präsentation wird die Zeit gemessen, die Sie brauchen, um auf die eingehenden Signale zu reagieren. Nach jedem Vortrag werden Sie gebeten, einen Fragebogen zu der verwendeten Benachrichtigungstechnik auszufüllen. Mehrere Parameter, wie z. B. die kognitive Belastung oder Ihr Ersteindruck werden untersucht.
Abschließend vergleichen und bewerten Sie die vorgestellten Benachrichtigungstechniken anhand eines weiteren Fragebogens und eines kurzen Interviews. Während der Präsentationen und des Interviews wird Ihr Audio aufgenommen.

**Zeit:** Die Studie wird vermutlich ca. 1 Stunde und 30 Minuten dauern.

**Risiken:** Sie werden mehrere Gelegenheiten haben, während des Studienverlaufs zusätzliche Erholungspausen einzulegen, wenn dies nötig ist. Wenn Sie die Aufgaben oder die Fragebögen als anstrengend empfinden, können Sie die Studie sofort abbrechen. Ihr Arm kann während der Studie ermüden oder die Positionierung des Geräts kann mit der Zeit etwas unangenehm werden. Daher können Sie das Gerät bei Bedarf in den dafür vorgesehenen Erholungspausen abnehmen oder die Position am Arm leicht verändern. Es sind keine weiteren Risiken im Zusammenhang mit der Studie bekannt.

**Bezahlung:** Sie werden keine Bezahlung für die Teilnahme an der Studie bekommen. Während und nach der Teilnahme gibt es Snacks und Getränke für Sie.

**Rechte des Teilnehmers:** Wenn Sie diese Einverständniserklärung gelesen haben und sich entschieden haben an der Studie teilzunehmen, beachten Sie bitte, dass die Teilnahme freiwillig ist und Sie das Recht haben Ihr Einverständnis jederzeit zu widerrufen oder die Teilnahme abzubrechen. Die Alternative ist nicht teilzunehmen. Sie haben das Recht sich zu weigern bestimmte Fragen zu beantworten. Ihre Privatsphäre wird geschützt in jeglichen veröffentlichten und geschriebenen Dokumenten, die aus der Studie hervorgehen. Alle während des Studienzeitraums erfassten Informationen werden streng vertraulich behandelt. Die Informationen werden durch Identifikationsnummern gekennzeichnet, sodass eine Rückverfolgung zu den Teilnehmenden als Person nicht mehr möglich ist. Die Veröffentlichungen oder Berichte zu diesem Projekt werden keine Informationen beinhalten, die Rückschlüsse auf die einzelnen Teilnehmer zulassen.

**Kontaktinformation:**
Falls Sie sonstige Fragen, Bedenken oder Beschwerden bzgl. der Studie, deren Verfahren und Risiken haben, kontaktieren Sie Ulyana Lavnikevich (ulyana.lavnikevich@rwth-aachen.de).

**Figure A.1:** Informed Consent Form. (Page 1)

## Einverständniserklärung

Ich bin damit einverstanden, dass während dieser Studie Tonaufnahmen durchgeführt werden:

Zutreffendes bitte ankreuzen: ☐ Ja ☐ Nein

Ich habe alles gelesen und erklärt bekommen:

Zutreffendes bitte ankreuzen: ☐ Ja ☐ Nein

**Name** ______________________ **Unterschrift** __________________ **Datum** ____________

**Name des Studienleiters** ______________________ **Unterschrift** __________________

**Figure A.2:** Informed Consent Form. (Page 2)

Participant ID: ___________

## LED-Ring

**Beurteilung der Benachrichtigungstechnik** (Armband mit LED-Ring)

Geben Sie jetzt für jede der unten stehenden Kategorien an, wie hoch die Beanspruchung war. Markieren Sie dazu bitte auf den folgenden Skalen, in welchem Maße Sie sich in den sechs genannten Kategorien von der Aufgabe beansprucht oder gefordert gesehen haben. Ein Beispiel:

X

gering hoch

**Geistige Anforderungen**
Wie viel geistige Anstrengung war bei der Informationsverarbeitung erforderlich (z.B. Denken, Erinnern, Hinsehen)? War die Aufgabe leicht oder anspruchsvoll, erforderte sie hohe Genauigkeit oder war sie fehlertolerant?

gering hoch

**Körperliche Anforderungen**
Wie viel körperliche Aktivität war erforderlich (z.B. Ziehen, Drücken, Steuern, Aktivieren)? War die Aufgabe leicht oder schwer, einfach oder anstrengend, erholsam oder mühselig?

gering hoch

**Zeitliche Anforderungen**
Wie viel Zeitdruck empfanden Sie hinsichtlich der Häufigkeit oder dem Takt, mit dem Aufgaben oder Aufgabenelemente auftraten? War die Abfolge langsam und geruhsam oder schnell und hektisch?

gering hoch

**Leistung**
Wie erfolgreich haben Sie Ihrer Meinung nach die vom Versuchsleiter (oder Ihnen selbst) gesetzten Ziele erreicht? Wie zufrieden waren Sie mit Ihrer Leistung bei der Verfolgung dieser Ziele?

gut schlecht

**Anstrengung**
Wie hart mussten sie arbeiten, um Ihren Grad an Aufgabenerfüllung zu erreichen?

gering hoch

**Frustration**
Wie unsicher, entmutigt, irritiert, gestresst und verärgert (versus sicher, bestätigt, zufrieden, entspannt und zufrieden mit sich selbst) fühlten Sie sich während der Aufgabe?

gering hoch

**Figure A.3:** User study questionnaire (Page 1). The questionnaires are structured analogously for all modalities.

Participant ID: __________

Nachfolgend finden Sie Wortpaare, mit deren Hilfe Sie die Beurteilung vornehmen können. Sie stellen jeweils Gegensätze dar, zwischen denen eine Abstufung möglich ist. Bitte markieren Sie zwischen den folgenden Wortpaaren, wo Sie die Nutzung dieses Geräts während des Vortrages einordnen. Ein Beispiel:

unangenehm ○ ○ ○ ● ○ ○ ○ angenehm

| | | |
|---|---|---|
| behindernd | ○ ○ ○ ○ ○ ○ ○ | unterstützend |
| kompliziert | ○ ○ ○ ○ ○ ○ ○ | einfach |
| ineffizient | ○ ○ ○ ○ ○ ○ ○ | effizient |
| verwirrend | ○ ○ ○ ○ ○ ○ ○ | übersichtlich |
| langweilig | ○ ○ ○ ○ ○ ○ ○ | spannend |
| uninteressant | ○ ○ ○ ○ ○ ○ ○ | interessant |
| konventionell | ○ ○ ○ ○ ○ ○ ○ | originell |
| herkömmlich | ○ ○ ○ ○ ○ ○ ○ | neuartig |

Bitte kreuzen Sie pro Aussage ein Kästchen an, das Ihrer Meinung nach am ehesten zutrifft:

| | stimme gar nicht zu | stimme eher nicht zu | neutral | stimme eher zu | stimme voll zu |
|---|---|---|---|---|---|
| Die Benachrichtigungen waren einfach zu interpretieren | ☐ | ☐ | ☐ | ☐ | ☐ |
| Ich konnte zwischen drei verschiedenen LED-Farben unterscheiden | ☐ | ☐ | ☐ | ☐ | ☐ |
| Ich habe auf die Benachrichtigungen schnell reagiert | ☐ | ☐ | ☐ | ☐ | ☐ |
| Ich habe oft auf das Armband geschaut | ☐ | ☐ | ☐ | ☐ | ☐ |
| Die Benachrichtigungen haben mich während des Vortrages nicht abgelenkt | ☐ | ☐ | ☐ | ☐ | ☐ |
| Ich bin mir sicher, dass ich alle Benachrichtigungen wahrgenommen habe | ☐ | ☐ | ☐ | ☐ | ☐ |

**Figure A.4:** User study questionnaire (Page 2). The questionnaires are structured analogously for all modalities.

Participant ID: ___________

Was hat Ihnen an der vorgestellten Benachrichtigungstechnik gefallen?

Was hat Ihnen an der vorgestellten Benachrichtigungstechnik nicht gefallen?

Wie könnte man die Benachrichtigungstechnik verbessern?

Weitere Anmerkungen:

**Figure A.5:** User study questionnaire (Page 3). The questionnaires are structured analogously for all modalities.

Participant ID: ________

**Zum Abschluss beantworten Sie bitte noch folgende Fragen zu Ihrer Person bzw. Ihren Vorkenntnissen und zur Bewertung der vorgestellten Benachrichtigungstechniken:**

Alter: ______

Geschlecht: _________________

Dominante Hand: ☐ Linkshänder ☐ Rechtshänder

Beruf / Studium: _________________________________

Wie gerne halten Sie Vorträge und Präsentationen?

| Sehr gerne | Gerne | Neutral | Ungerne | Sehr ungerne |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

Wie oft halten Sie Online-Präsentationen?

| Mehrmals in der Woche | Mehrmals im Monat | Mehrmals im Jahr | Selten | Nie |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

Wann haben Sie letztes mal online eine Präsentation gehalten?

| Vor ein paar Tagen | Vor ein paar Wochen | Vor ein paar Monaten | Vor ein paar Jahren | Nie |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

Bitte erstellen Sie eine Rangliste der getesteten Benachrichtigungsarten (die Ränge 1 bis 4 dürfen nur einmal vergeben werden, dabei ist 1 der beste und 4 der schlechteste):

| Ohne Armband | LED-Ring | Vibration | Tonsignal |
|---|---|---|---|
| | | | |

Begründen Sie kurz, warum Sie diese Auswahl getroffen haben?

**Figure A.6:** Final questionnaire.

# Appendix B

# Likert Scale Results

Results for the question *"I have often looked at the wrist-worn device."* are inverted because positive responses to the questions should be displayed in green.

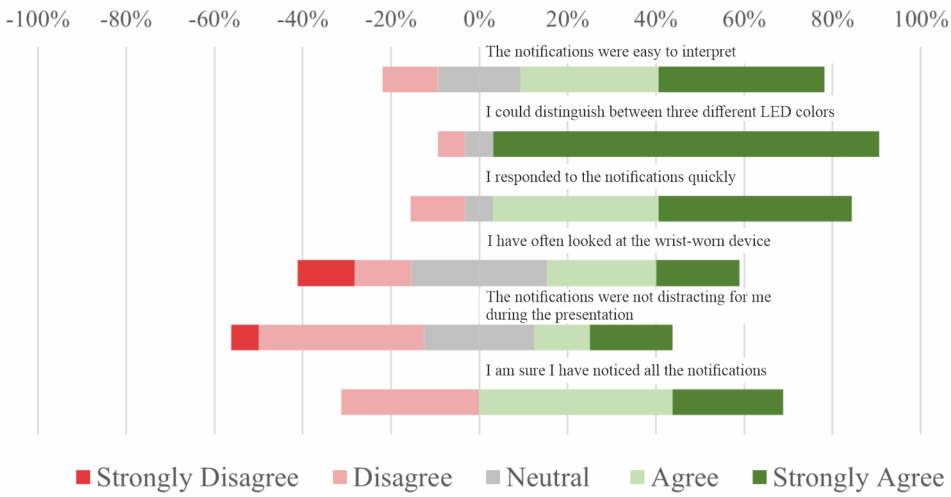


**Figure B.1:** Likert scale results for the LED.

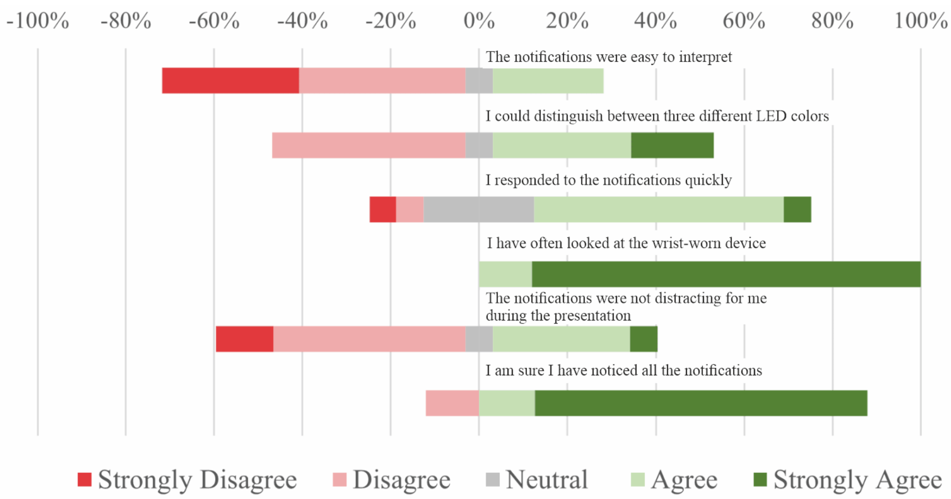


**Figure B.2:** Likert scale results for the Vibration.

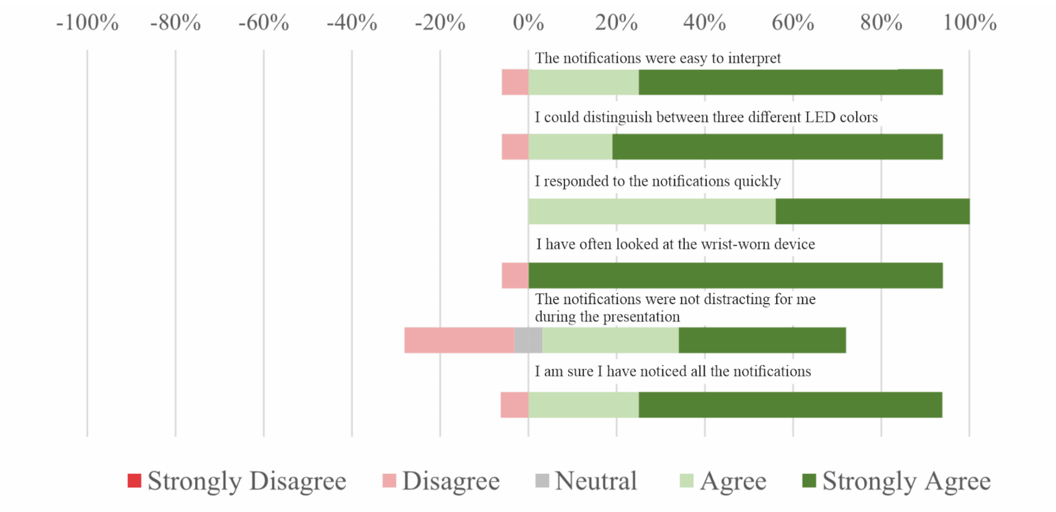


**Figure B.3:** Likert scale results for the Sound.

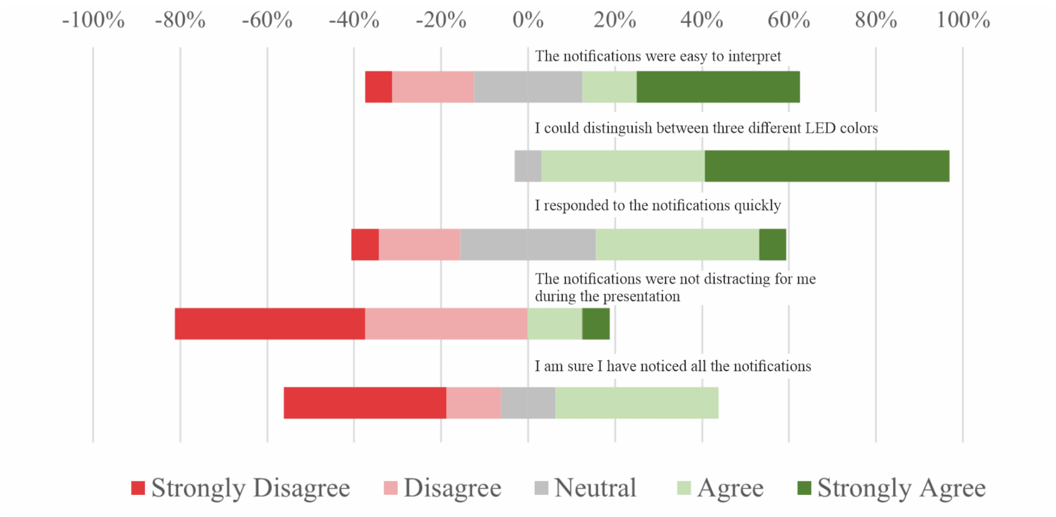


**Figure B.4:** Likert scale resulta for the Baseline.

# Appendix C

# Software

In the following link, the Arduino, Python, and files for the 3D-printed components can be found.

https://bit.ly/3sl3i4G

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