Improving the Ergonomic Working Conditions of Ophthalmologists

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Integrated Product Design

TU Delft - Master's Thesis

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0.1 Summary

In this master's thesis in collaboration with *het Nederlands Oogheelkundig Gezelschap* (NOG), or the Dutch ophthalmic society, I developed an industrial design concept to improve the ergonomic working conditions of Ophthalmologists.

25% of Dutch Ophthalmologists (surgical eye doctors) have suffered from musculoskeletal injuries (MSIs) during their careers, according to research by NOG. As a result of my research, including interviews with 14 Ophthalmologists currently employed in Dutch medical institutions, I concluded that 5 out of the 7 musculoskeletal injuries, experienced by Ophthalmologists, are in the back, shoulders and neck area. The concluded causes of these MSDs are equipment that does not accommodate for doctor/patient height differences, and neglect of personal health in favour of patient satisfaction.

Height Matcher is a redesign of the ophthalmic examination unit, integrating patient chair and equipment table, and upgrading their capabilities. The repositioning of components also allows the ophthalmologist to do standing examinations. The concept was validated through various user tests and expert interviews.

By extending the height range that the unit can be set to, speeding up its adjustment, and introducing a separate eye height measurement, height Matcher enables the ophthalmologist to maintain an ergonomic posture during examination, without sacrificing patient satisfaction or comfort.

With the concept, an ophthalmologist will have their eye height measured at the start of their career. This is done by a second person, ensuring proper posture and measurement. They measure the sitting and standing eye heights.

When the ophthalmologist goes to work in the outpatient clinic, the two eye heights are dialled into the data profile using the interface panel on the examination unit. The equipment table moves to bring the eyepiece to the ophthalmologist's eye height.

When the patient comes in, the ophthalmologist can adjust the patient's chair forwards/backwards and up/down depending on the patient's proportions.

If the ophthalmologist wants to examine the patient in standing position, they press the mode change button, to transition from sitting to standing mode. The patient chair and slit lamp table move up proportionally, to maintain their relative distance, for seamless working.

The doctor examines the patient as usual, with good ergonomic posture for both.

Contents.

I am Yan

I would like to thank my team, as well as all the experts and medical specialists who gave me their time during this thesis. My company contact Daphne Albers and her colleagues at NOG, academic chair Pieter Jan Stappers, academic mentor Gonny Hoekstra, the various Ophthalmological clinics that I was fortunate enough to visit and their Ophthalmologists who allowed me to observe their work, the helpful team at MID, the industry representatives that gave me their time during this project and the many others that helped me in the past months.

Chapters.

Introduction.

This is a master's thesis for Integrated Product Design, TU Delft, with the goal of improving the ergonomic working conditions of Ophthalmologists in the Netherlands.

Chapter 1.

6. pages

1.0 Introduction

Introduction

This master's thesis was done in partnership with NOG: The Dutch ophthalmic society (Nederlands Oogheelkundig Gezelschap: NOG). The NOG is the professional organisation for Ophthalmologists in the Netherlands. They are committed to protecting and advancing the field of ophthalmology in the Netherlands. The aim of NOG and its various commissions is to support Ophthalmologists in the Netherlands in their professional performance and work enjoyment; improving the quality of ophthalmic care in the Netherlands; promoting scientific research in care and cure; and advising on the use of new medication (NOG, n.d.). Members of the Dutch ophthalmic society include Ophthalmologists, ophthalmic residents and retired Ophthalmologists. The figure on the right shows a representation of a typical ophthalmologist in the Netherlands.

See the glossary at the end of this report for more information on medical terminology and other terms, used throughout this report.

Research by NOG shows that work-related musculoskeletal injuries (WMIs) are common among Ophthalmologists. This study showed a prevalence of work-related musculoskeletal injuries among Dutch Ophthalmologists, with around 25% suffering from physical complaints such as hernia, osteoarthritis, back pain and shoulder injuries (NOG, unpublished-a) These findings are supported by studies such as Roach (2020), who confirm that work-related musculoskeletal injuries are a pervasive problem in the sector; Kitzmann et al. (2012), who conclude a higher prevalence of neck, hand/wrist, and lower back pain in Ophthalmologists compared with other medical professions; and Hyer et al. (2015), in a national survey among Ophthalmologists in the United Kingdom concluding occurrence rates of 30% and up to 60% for several musculoskeletal injuries among its respondents. In addition to physical complaints, Ophthalmologists also deal with high stress levels, which is furthermore substantiated by studies such as Feng et al. (2018) and Feng et al. (2021), observing high levels of burnout in ophthalmology residents. Other studies like Garrido-Hermosilla et al. (2021) and Yu and Cheung (2020) show above average rates of burnout among Ophthalmologists when compared to other medical fields.

Adding to this already large incentive for change, according to research by PwC. (2022), employee well-being is the biggest impacting factor in company absenteeism and turnover reduction in the Netherlands. Workplace stress additionally ranks 4th in the same list. Improving employee well-being in Ophthalmologists is, therefore, not only a primary incentive for medical institutions, but also a monetary incentive.

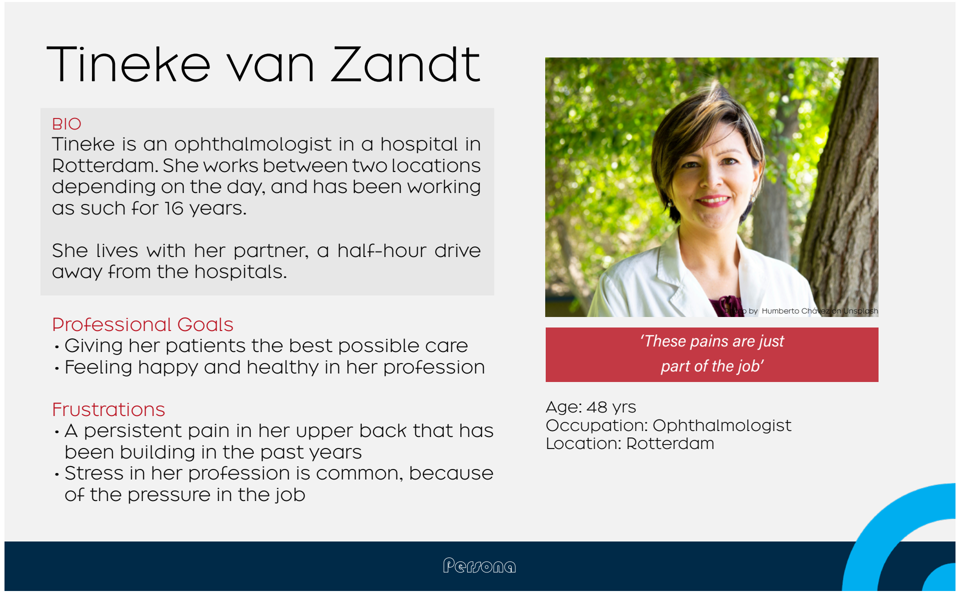


Figure 1.1: Averaged Persona of a Dutch Ophthalmologist

1.0 Introduction

Introduction

In this report, apart from the key demographic of Ophthalmologists, you will also find the professions Optometrist, physician assistant, technical ophthalmic assistant (TOA) and ophthalmic resident referred to. All these professions are united by providing specialistic medical care for the eyes. The differences are as follows.

Ophthalmologists have the highest level of specialist training and differ from the other professions in what they can diagnose and treat (Hull, n.d.) (Lentiamo.nl, 2024). An ophthalmologist is a medical doctor who diagnoses eye diseases, prescribes medication and performs surgery. They, together with PAs are the only professions that can prescribe medication.

Optometrists also perform a number of treatments. After identifying eye conditions, the Optometrist refers the client to the GP or ophthalmologist if necessary. Upon referral from the general practitioner or ophthalmologist, the Optometrist carries out follow-up examinations regarding eye disorders (OVN, n.d.). They examine the eyes for possible abnormalities. In the case of detected refractive errors, the Optometrist advises on necessary optical correction or aids, such as glasses and contact lenses, to eliminate, reduce or compensate for the error.

Physician assistants (PAs) are, in terms of qualifications and skills, between an ophthalmologist and an Optometrist. The PA may prescribe a number of medications and perform low-complexity, common routine procedures.

Technical ophthalmic assistants (TOA) are technical supporting staff in the medical setting. They carry out some of the examinations on behalf of Ophthalmologists. They work on the instructions of an ophthalmologist.

Ophthalmological residents are Ophthalmologists in training. They receive and diagnose patients under the supervision of a fully certified ophthalmologist.

Opticians are trained technicians, not qualified to diagnose or prescribe, but instead focus on the fitting of glasses. They generally do not work in a medical setting.

A further list of terms and abbreviations used throughout this report is included in the glossary in Appendix 25, at the end of this report.

1.1 Project context: Ophthalmology

Introduction

Ophthalmologists have 2 main working contexts. The outpatient clinic is where patients are first received, often having been referred by a GP or optician. Here they are examined, diagnosed, and prescribed treatments (figure 1.2, bottom left). The second working context is **the operating room** where patients undergo eye surgery (figure 1.3, bottom right). Most Ophthalmologists work in both contexts across different days and parts of the day.

Figure 1.2: Ophthalmologist examining patient through Slit Lamp using a separate retinal lens

Figure 1.3: Ophthalmologist performing surgery (Murdoch Ophthalmology, n.d.)

An average ophthalmic outpatient clinic appointment goes as follows. The patient is received in the waiting room and is called into the ophthalmologist's room (figure 1.4, top right) by the doctor, standing at the door. They will have already visited an Optometrist or other supporting staff member for preliminary checkups and administering of pupil-widening eye drops. These are administered to allow their eyes' interior to be examined without obstruction. Upon entering, they are asked to sit in the patient chair. The patient chair can be adjusted in height slightly to bring the patient's eyes level with the slit lamp.

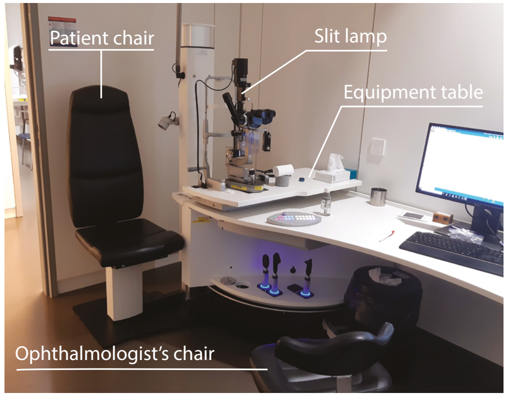


Figure 1.4: A typical ophthalmologist's clinic room

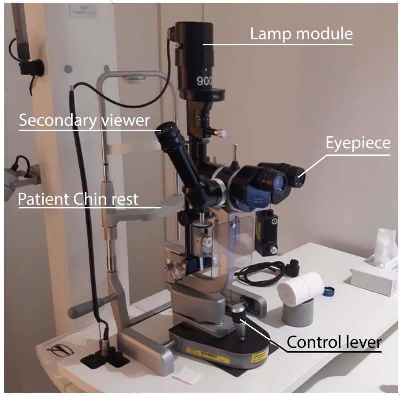


Figure 1.5: Different parts of a slit lamp

The slit lamp is the most common piece of examination equipment in an ophthalmologist's room (figure 1.5, top right). The eyepiece allows the doctor to look at and into the patient's eye with a set of magnifications. The control lever allows the ophthalmologist to minutely adjust the height and position of the viewer, relative to the patient's eye (figures 1.6 and 1.7, below). For more detailed information on these devices, see Appendix 6: Ophthalmological Clinic Analysis.

Figure 1.6: Ophthalmologists working with a slit lamp

Figure 1.7: Ophthalmologist working with a slit lamp, and a retinal lens (held up with the right hand)

1.1 Project context: Ophthalmology

Introduction

The ophthalmologist sits down at their desk. They discuss the patient's situation based on the medical file that is pulled up onto the doctor's computer screen (figure 1.9, next page). The ophthalmologist then asks the patient to sit back, pushing a button, making the slit lamp table slide in front of the patient, sometimes adjusting the height of the table and/or slit lamp to meet the patient. This same button push also dims the room lights and ignites the slit lamp light (Kaur, 2023). The slit lamp is used, with the doctor sitting across from the patient, with the slit lamp between them. The patient is asked to glance right, left, up and down, so the doctor can examine both eyes from all angles. The ophthalmologist then manually positions a separate lens between the slit lamp and patient's eye to change magnification, so that they can examine the retina (Figure 1.10, next page, bottom). This is called a retinal exam.

The lens is moved slightly by the doctor to examine different parts of the retina. When the slit lamp examination is finished, the patient sits back, the slit lamp table slides away to the side, the ophthalmologist enters new information in the patient's file and communicates the subsequent treatment procedures to them. The patient gets up and walks out back into the waiting room, often planning a return appointment. The doctor does further administration and when finished, gets up to call in the next patient. **The entire appointment takes less than 10 minutes per patient** on average (NOG, unpublished-b). While first appointments take longer than return appointments, and slight variances exist between doctors and institutions, this is the average.

The visual below shows a **schematic representation of the ophthalmic outpatient clinic**, as described.

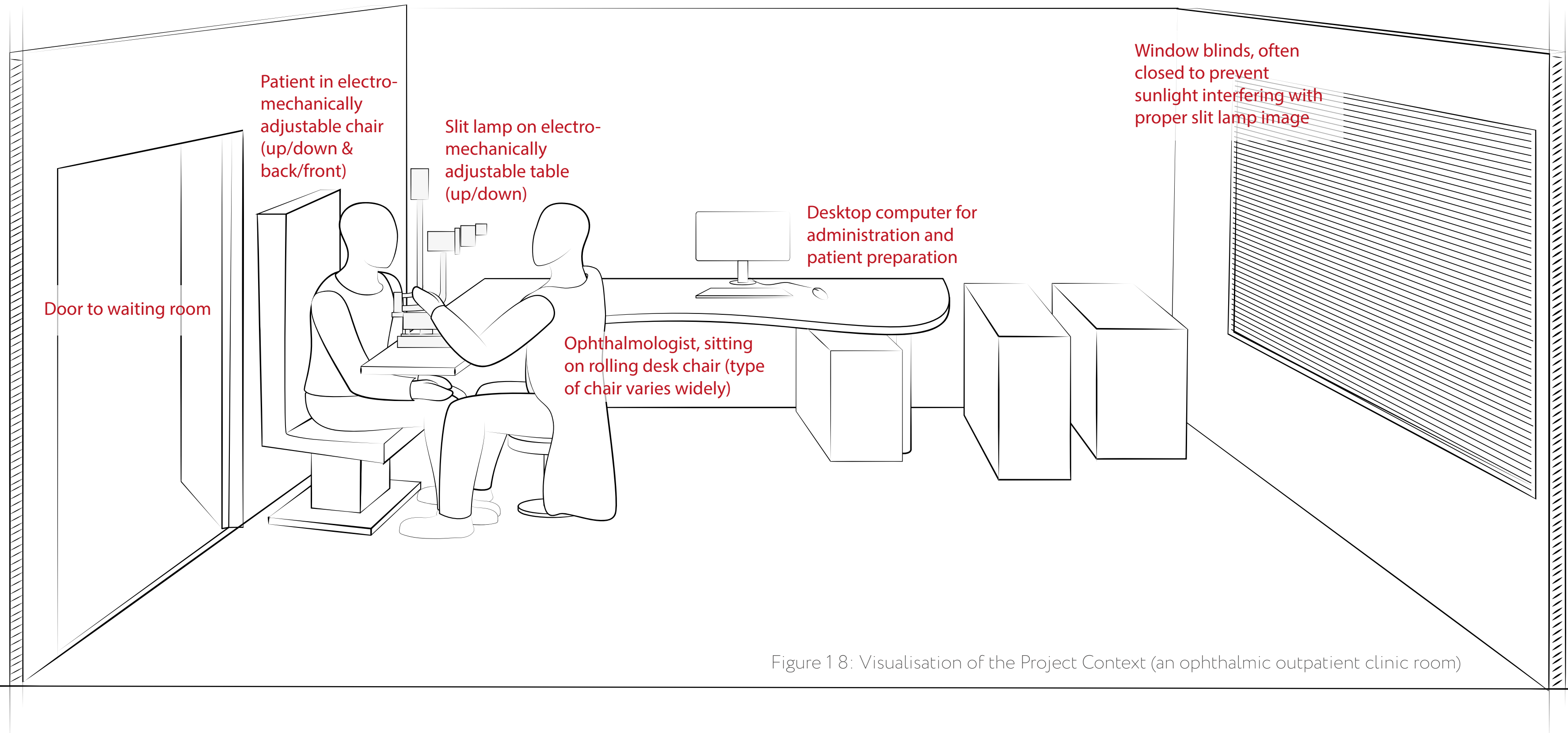


Figure 1.8: Visualisation of the Project Context (an ophthalmic outpatient clinic room)

1.2 Project Goal: Improving Ergonomics

Introduction

Work-related musculoskeletal injuries are common among Ophthalmologists, with 25% of Dutch Ophthalmologists suffering from some type, according to a study by NOG (NOG, unpublished-a). The doctors who suffer from them, often have to work reduced hours. 32% Of respondents in the study by NOG related having Ophthalmologists in their department working reduced hours due to physical and psychological complaints in the past 6 months. Some leave the profession entirely. This further exacerbates the already present shortage of qualified Ophthalmologists and makes the long waiting lists for patients even longer, in turn further increasing work pressure for Ophthalmologists in the field. The goal of this project therefore is:

Design a solution that will improve the long-term well-being of Ophthalmologists by improving the physical ergonomics of their daily, work-related activities

The focus is thus on the well-being of the Ophthalmologists. Improvement of the physical ergonomics is the tool to realise this. Daily, work-related activities is included to signify the aim is to improve the work-related well-being. Non-work-related activities are out-of-scope.

Another factor that is influential is the high work-pressure in ophthalmology. While many Ophthalmologists mention this as a catalyst for work-related complaints, it is outside the scope of this project to inherently solve, as it involves many factors, such as employee shortages in the medical sector (NOS, 2022) and an aging population requiring more care (Sterenborg, 2023) (NOG & Van Liempt, n.d.). While this factor is out of scope to solve through this project, it is nonetheless an important context factor to stay aware of.

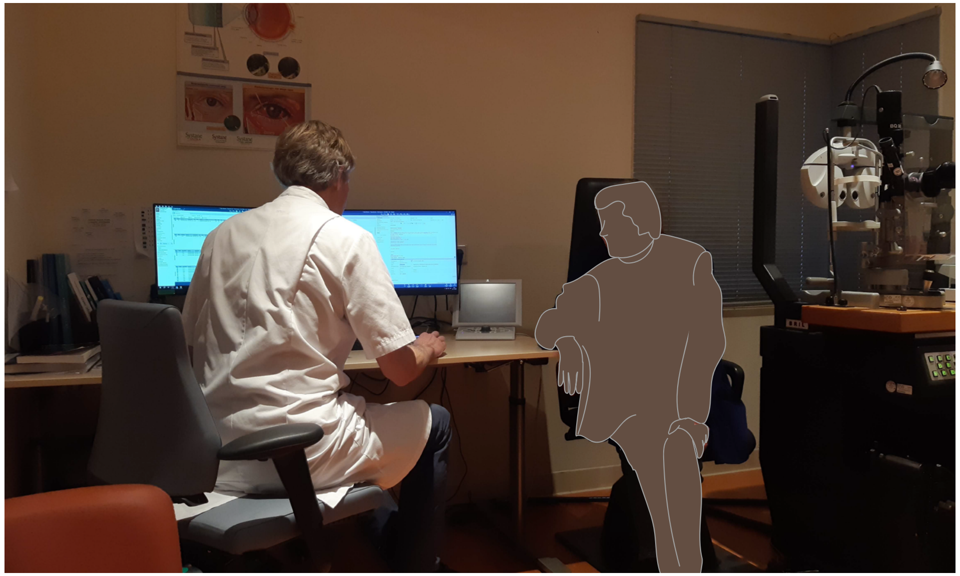


Figure 1.9: Ophthalmologist talking to a patient

Figure 1.10: Retinal lenses. A separate lens that is held up between the slit lamp and patient's eye by the ophthalmologist to change magnification, so the doctor can examine the retina. This is called a retinal exam.

1.3 Approach and Planning

Introduction

In this report, after the introduction, you will first read a synopsis of the final design in Chapter 2.

In Chapter 3 I describe the Research phase, in which I identified key factors that cause work-related musculoskeletal injuries in Ophthalmologists, and identified promising Problem spaces to design for in the next phase.

In Chapter 4 I elaborate on the subsequent Design phase, in which I developed solutions and concepts that can address and solve the problems identified in the research phase. I then embodied the chosen design concept into a full-fledged design proposal.

In Chapter 5 I include Recommendations for further detailing to produce the concept in the future; advice to the sector on how to improve Ophthalmologists' long-term health with the means currently available, according to my research; and a list of future research opportunities.

Chapter 6 includes my Acknowledgements to the people that helped me realise this thesis, and Chapter 7 includes my Sources.

Appendices 1 through 4 include documents such as the initial Assignment, my graduation proposal, and documents on project ethics. Appendices 5 through 12 span the process from Pre-research, Context analysis, Research Script and Results and the resulting List of requirements. Appendices 13 through 24 span the process from Design directions to Conceptualisation, User testing and finally Technical drawings. The Appendices are ended with a Glossary in Appendix 25.

My planning and approach to this project is schematically described in figure 1.11 on the right.

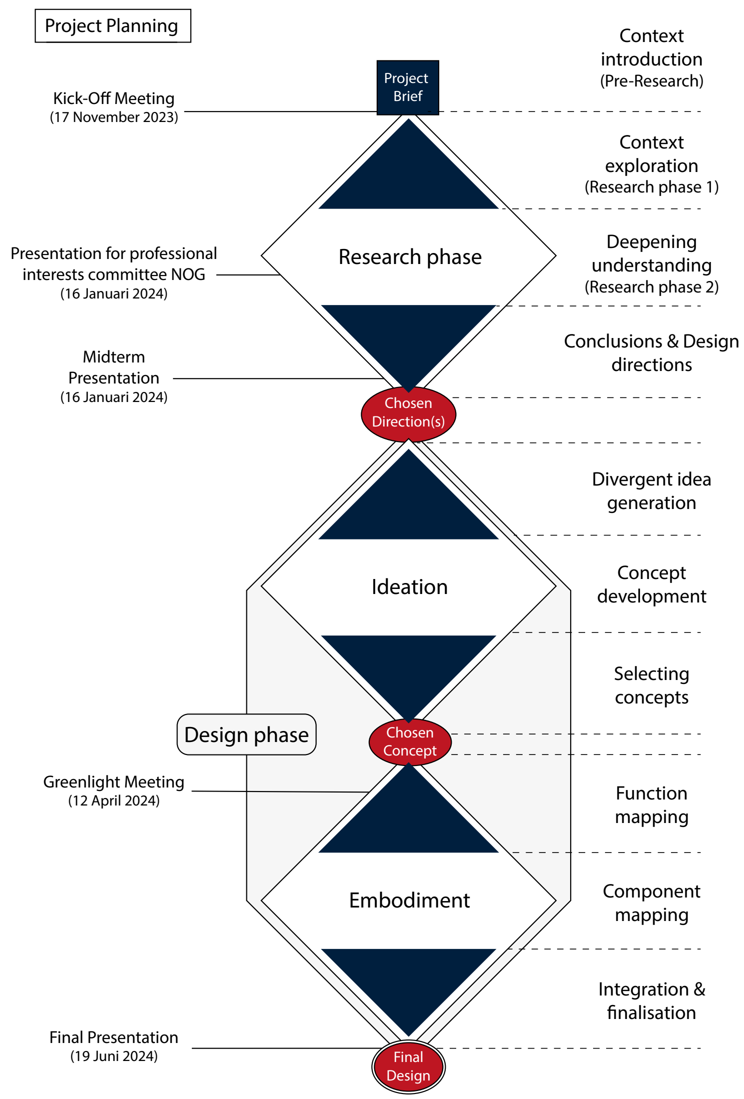


Figure 1.11: Schematic description of project planning and approach. Two main phases are embodied in the planning: Research, and Design. These phases also form the two biggest chapters in this report. Important project presentations are shown on the left of the figure and descriptions of the project activities are included on the right

Final Design.

Concept presentation

Chapter 2.

2 Final Design

Final Design

Height Matcher is **a redesign of the ophthalmic examination unit** with ergonomic posture for both ophthalmologist and patient as a priority. It integrates the patient chair and slit lamp table into a single unit and upgrades their adjustability in several ways to benefit both doctor and patient.

By **extending the height adjustment range** of the unit and simplifying the interaction, it enables both the ophthalmologist and patient to maintain ergonomic posture during examination. The extended height adjustment range even allows the doctor to seamlessly examine the patient while standing up, swapping from sitting to standing mode with the click of a button.

By integrating **an eye height measurement** in the ophthalmologist's on-boarding procedure, and **a quantified table height** on the interface, the doctor is better able to quickly and easily adjust the equipment to their own height, without compromising examination accuracy or patient satisfaction.

By using a **motorised rotating table top**, instead of a more conventional linear movement, the unit allows **wheelchair users** to be examined in the same way that other patients are. The doctor is thus no longer required to use the more strenuous hand-held examination tools. The short, rotating table top also significantly reduces the total footprint of the unit compared to existing alternatives. The reduced footprint enables it to be installed in a wider variety of clinics and provides more flexible placement options in examination spaces. With more flexibility regarding placement, the ergonomic needs of Ophthalmologists can be considered more effectively than what is possible with current solutions. It allows the unit to be installed in line with the ophthalmologist instead of the suboptimal perpendicular positioning that is often necessary with existing units.

Figure 2 1: Height Matcher, an ergonomics focussed redesign of the ophthalmic examination unit

Research Phase.

The aim of this phase is to get immersed in, and gained an understanding of the problem context to then establish well founded design directions for the subsequent design phase.

Chapter 3.
15. pages

3.1 Scope, Goal and Questions

Research phase

Ophthalmology has two sides: the outpatient clinic where patients are examined, diagnosed, and prescribed treatments; and the operating room where patients undergo eye surgery. With the available time for this project, it would be an unrealistic goal to reach a detailed level of knowledge on both the outpatient clinic as well as the complex context of an ophthalmic surgery room. All Ophthalmologists work in outpatient clinics, and all ophthalmic patients get examined there, even if no surgery is done. Gaining an understanding of the outpatient clinic, and designing a solution for this context, therefore has a higher potential to help Ophthalmologists. The result also has a higher chance of being valuable beyond its ophthalmological context, as the pieces of equipment in the ophthalmic clinics such as the slit lamp, eye pressure monitor, patient unit etc. are also used by Optometrists and opticians. This is why **I narrowed the scope to only the outpatient clinic.**

With the project goal of designing a solution to improve Ophthalmologists' work-related well-being, the goal of this research phase is to find out what is currently the problem; and what is the cause of this, to be able to design solutions for this/these problem(s) in the next phase. The main research question therefore, is as follows.

What are the work related factors in the ophthalmological outpatient clinic process that cause physical complaints for Ophthalmologists?

This main research question is answered by answering the following sub-research questions.

1) Which work-related physical complaints are most common among Ophthalmologists?

2) What are the work-related risk factors that contribute to physical complaints?
   a.) What physical workplace properties contribute to the complaints?
   b.) What work-related behavioural patterns contribute to the complaints?
   c.) What work-related logistical circumstances contribute to the complaints?

3) What measures are Ophthalmologists currently taking to prevent or reduce physical complaints?

4) What is the stance of healthcare institutions as to the ergonomic working conditions of Ophthalmologists, and what measures are being taken to protect them?

As shown in these questions, I first determine what the problems are. I then list what contributes to these problems, splitting this list into three distinct sections concerning the equipment itself, how the workplace is used and how institutional rules, regulations and advice influence the workplace. After thus determining cause and effect, I will determine how Ophthalmologists are currently solving these problems themselves. To design solutions, it is important to understand how users are currently solving the problem themselves. I will then determine how their employers are attending the problem. Similar to the previous sub-question, it is important to understand how the users' employers are currently approaching the problem. By answering these sub-questions, I will gain an understanding of the context and the problems, to then design for it.

3.2 Expectations

Research phase

My expectations for the research were mostly formed by two visits to ophthalmic hospitals. One for a conversation with an ophthalmologist in their outpatient clinic in Rotterdam, and the second, a visit to the medical instrument technicians (MID) at Oogziekenhuis Rotterdam. The ophthalmologist I visited is also a member of the professional interests committee with specific responsibility for ergonomics within Dutch ophthalmology. The medical instrument technicians provide ophthalmic equipment maintenance, specialising in yearly slit lamp maintenance, for several medical institutions in the Netherlands. The findings from these visits were strengthened by literature review.

My expectations were as follows:

1)
Most common physical complaints: Wrist and hand complaints
This expectation was based on the conversation with the ophthalmologist in Rotterdam.

2)a.
Physical workplace properties that contribute to the complaints: The small adjustment knobs and levers, and insufficient adjustment possibilities on the slit lamp require harmfully repetitive small hand movements.
This expectation was based on the conversation with the ophthalmologist in Rotterdam and MID. They underscored the repeated fine hand movements needed to adjust the device as a problem area causing MSDs. This was confirmed by Roach (2020) and Hyer et al. (2015), whom point at repetitive tasks using fine motor control and awkward prolonged working postures as causes of work-related musculoskeletal injuries.

2)b.
Behavioural patterns: Ophthalmologists respond to the high work pressure in their profession by prioritising productivity and patient satisfaction over their own health and well-being.
This expectation was based on the interview with the medical instrument technician, whom mentioned that many Ophthalmologists adjust their own posture to their patient's comfort. Long et al. (2011) confirms this, pointing at a greater number of eye examinations per day, increasing the risk of reporting work-related discomfort by up to 5.1.

2)c.
Logistical circumstances: Unclear advice and support in terms of ergonomic working conditions from medical institutions leaves Ophthalmologists to their own devices.
This expectation was based on the conversation with the ophthalmologist in Rotterdam.

3)
Current measures from Ophthalmologists: High work pressure leaves little time to influence working conditions for the better. Symptomatic solutions such as regular exercise are favoured.
This expectation was based on the interview with the technician at MID, as well as the conversation with the ophthalmologist in Rotterdam.

4)
Current stance of healthcare institutions: Healthcare institutions are conservative and with priorities focussed on patient satisfaction, employee needs can become overlooked. Thus, changes in favour of ergonomic working conditions are implemented slowly, if at all.
This expectation is based on the conversation with the ophthalmologist in Rotterdam. Sterenborg (2023) also mentions that current outflow of medical personnel could be curbed by improving ergonomics in the workplace.

3.3 Method

Research Phase

Visits to ophthalmology clinics were chosen over other methods, to answer the research questions, as it provides a more detailed understanding of the problem context. This is in contrast to for instance an online questionnaire. While this might have reached more people, in-person observations and interviews with the problem owners, Ophthalmologists, were chosen to gather rich, detailed information, as opposed to numerous, less detailed replies.

Observations were made to gain an understanding of the context; interviews with Ophthalmologists were conducted to enrich and verify observational findings; and literature review was done as an addition, to further confirm observational and interview findings.

3.3.1 Respondents & recruitment

Respondents were recruited through NOG's contacts with the intent of establishing a diverse research population in terms of gender, years in the profession and type of employer institution. With eighteen Ophthalmologists contacted, visits to fourteen Ophthalmologists across nine separate medical institutions were finally realised.

These **respondents are currently employed at a Dutch medical institution**, with varying lengths of careers. Employers can be any of three types: hospital, independent treatment centre (ZBC, Dutch abbr.) or University Medical Centre (UMC). Hospitals are characterised by a mix of immediate medical emergency care and planned care. ZBCs are private healthcare institutions characterised by planned care. UMCs are hospitals connected to a university, and are defined by their educative role, as well as the complexity of care they can provide. These types of institutions' characteristics and respective differences are further elaborated on in the glossary at the end of this report. Respondent characteristics are included in the table on the right.

Table 3 1: Respondents' characteristics: Grouped by Research phase and sorted by Type of Institution

Institution	Type of Institution (1. Hospital, 2. ZBC, 3. UMC)	In training? (specialisation training)	Gender (m, v, x)	Years in profession (incl. other employers)	Respondent number
Research Phase 1					
IJsselland Ziekenhuis	1. Hospital		v	19	1
Gelre Ziekenhuizen Appeldoorn	1. Hospital		m	11	4
	1. Hospital		m	7.5	5
Alrijne Ziekenhuis Leiderdorp	1. Hospital		v	22	6
Eyescan Rijswijk	2. ZBC		v	13	2
	2. ZBC		v	15	3
Erasmus MC	3. UMC	x	v	2	7
	3. UMC		v	14	8
Research Phase 2					
Amphia Ziekenhuis Breda	1. Hospital	x	m	4	9
	1. Hospital		m	30	10
	1. Hospital		v	18	11
Franciscus Gasthuis / Vlietland	1. Hospital		m	22	13
Xpert Clinics	2. ZBC		v	1.5	14
UMC Utrecht	3. UMC		m	20	12
		Total		**Average**	
		2		15.8	

3.3.2 Ethics

The ethics checklist as well as the informed consent form used during research visits are included in Appendices 3 and 4 respectively.

3.3.3 Procedure

The research is split into two phases. The list of observational prompts and interview questions for both phases is formulated to answer the sub-research questions. The second phase is differentiated from the first by an addition of extra questions, that were formed by new gained understanding from the first phase. This second phase is meant to verify and enrich findings from the first phase.

3.3 Method

Research Phase

In the script, included in Appendix 7, lines that were added in the second phase are underscored. This Appendix also states, for every individual prompt and question, what sub-research question it is formulated for. For every line that was added in phase 2, it states what phase 1 result it is built upon.

3.3.4 Activities and environment

All **observations and interviews are conducted in the Ophthalmologists' usual working contexts**, their outpatient clinics. After an introduction of the project and research aims, the ophthalmologist is asked to continue working as usual, receiving, and treating patients, doing administration and any other regular activities.

3.4 Research Phase 1

Research Phase

3.4.1 Observations

Structured observations are made of the ophthalmologist's actions while they are receiving, and treating patients, doing administration and any other regular activities.

Observational prompts focus for instance on the equipment and chairs used, the way in which the doctor works with them, and the layout of the room. Maps such as the one below were also made of the visited Ophthalmologists' rooms. These are included in Appendix 9. Observational prompts are outlined in the script.

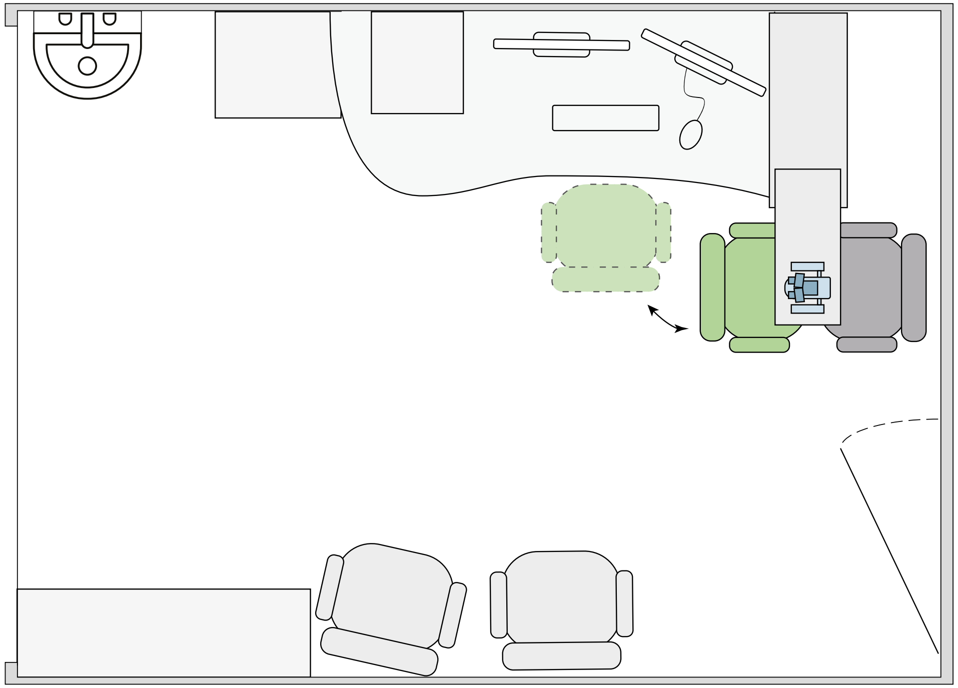


Figure 3 1: Map of a visited Ophthalmologist's room

3.4.2 Interview questions

After observation, an interview is conducted, to confirm and enrich the observational findings. Interview questions focus for instance on whether they have lasting physical complaints and what kind, whether these are work related, when in their career they started and what caused them, and what is done to combat these problems.

This interview is one on one, without patients present, to not impact quality of treatment for the patients. Time pressure is high in ophthalmology, which can make in-depth interviewing on-site a challenge. A degree of flexibility is therefore required in choosing the right time to ask questions. In general, it is best to ask questions in a semi-structured manner, in between patient visits as between administration, medical updates, and preparation for the next patient some time is usually available.

If there is still too little time on site, it can be fitting to propose an alternative time to finish the interview. Either after visitations, on another occasion or on a phone call at a later date.

The interview questions are formulated to answer the sub-research questions. The script mentions for every question what sub-research questions they are meant to answer.

3.4.3 Results phase 1

The results from the first phase of observations and interviews are listed below.

1.) While performing retinal exams with a separate lens to the slit lamp (figure 3.2, next page left), the hand and arm tend to be unsupported. This can lead to tension, and a build-up of strain in the arms, shoulders, and neck. Often an elbow rest is present (figure 3.3, next page left), but this solution still leaves tension in parts of the arm.

3.4 Research Phase 1

Research Phase

Figure 3 2: (left) Ophthalmologist using separate lens for retinal exam

Figure 3 3: Elbow support pads. Ophthalmologists use these to rest their elbow during retinal exams

2.) Some doctors make adjustments to the slit lamp and surrounding equipment during the day. This is either done to fine-tune for their own comfort or to accommodate the patient.

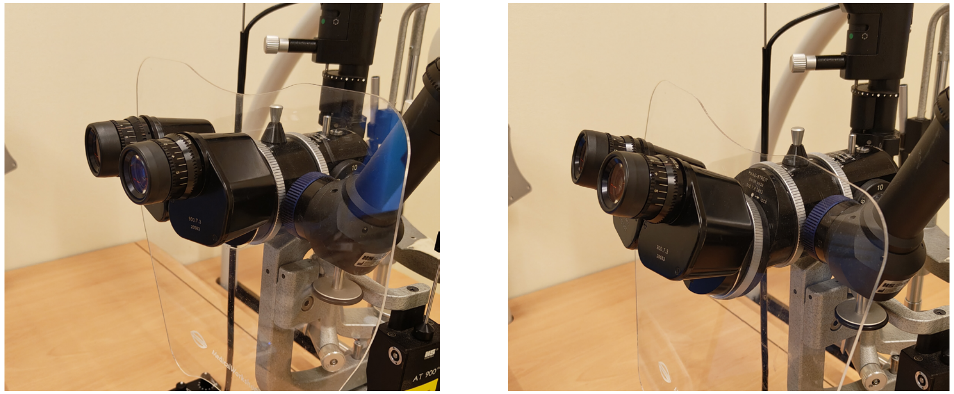


Figure 3 4: Slit lamp without corner piece (left) & with corner piece (right). The corner changes the direction of the eyepiece from horizontal to slightly upwards

3.) A corner piece is often present in ophthalmic rooms to change the direction of the eyepiece from horizontal to slightly upwards (figure 3.4, bottom left). Some Ophthalmologists highly prefer these while others never use them.

4.) The amount of supporting staff present (TOAs, Optometrists, or residents), appears to change the amount and nature of the work pressure. More supporting staff seems to result in fewer physical complaints for the ophthalmologist. However, the higher degree of responsibility, and more managerial duties seem to add their own sense of pressure to the ophthalmologist's work.

5.) No clear institutional guidelines or advice seem to exist for proper ergonomic working.

These findings formed the basis for the added prompts and questions in phase 2.

3.5 Research Phase 2

Research Phase

The goal of this second phase is to verify and enrich findings from the first phase. It is differentiated from the first by an addition of extra prompts and questions, that were formed by new gained understanding from the first phase. In the script, included in Appendix 7, lines that were added in the second phase are underscored.

3.5.1 Observations

Two observational prompts were added in the second phase. Firstly to observe whether the doctor adjusts the slit lamp at the beginning of the day, and whether further adjustments are made throughout the day. I aimed to determine why extra adjustments are made.

Secondly, to observe how the Ophthalmologists use the separate lens during retinal exams. An unsupported hand and arm here can lead to tension, and a build-up of strain. I aimed to determine how prevalent an issue this is.

3.5.2 Interview questions

Several questions were added in phase 2. Most notably I asked whether the equipment is properly adjusted, and when and for what reason the respondents adjust the slit lamp and surrounding equipment. This is based on one of the phase 1 results, and I aimed to determine why extra adjustments are made.

I also aimed to confirm the phase 1 result that no clear institutional guidelines exist for ergonomic working by asking respondents if they are aware of any.

Thirdly I added more questions about respondents' opinion on the equipment and whether they would wish to change anything. More details are included in the script.

3.5.3 Results phase 2

A list of results from the second phase of observations and interviews is included below.

1.) Ophthalmologists regularly adjust the equipment to patients instead of themselves.

2.) More Ophthalmologists confirm that retinal exams with the separate lens are strenuous and cause them complaints.

3.) No correlation is observed between Ophthalmologists' time in the profession and degree of experienced work-related musculoskeletal injuries.

4.) The correlation between amount of supporting staff present and the amount and nature of the work pressure and experience work-related musculoskeletal injuries is claimed by more Ophthalmologists but disregarded by others

This list of results as well as the first one are used in the next sub-chapter to form the full list of results.

3.6 Full Results

Research Phase

In this sub-chapter I will present the full list of results from the observations and interviews. This results list was summarised by relevance for the design project. Some of the results from phase 1 were reconfirmed and are included here, others are amended with new information from phase 2. The unabridged list of results is included in Appendix 10.

3.6.1 Results – Observations

This paragraph contains the abridged list of results from the observations.

Observational prompt 2: Does the layout of the room make the doctor turn around regularly during patient visits to talk to patients/supervisors or otherwise?
4 out of 8 mapped rooms are set up with the patient flanking the doctor, making them turn around regularly. In every one of these rooms, companions are seated behind the doctor.

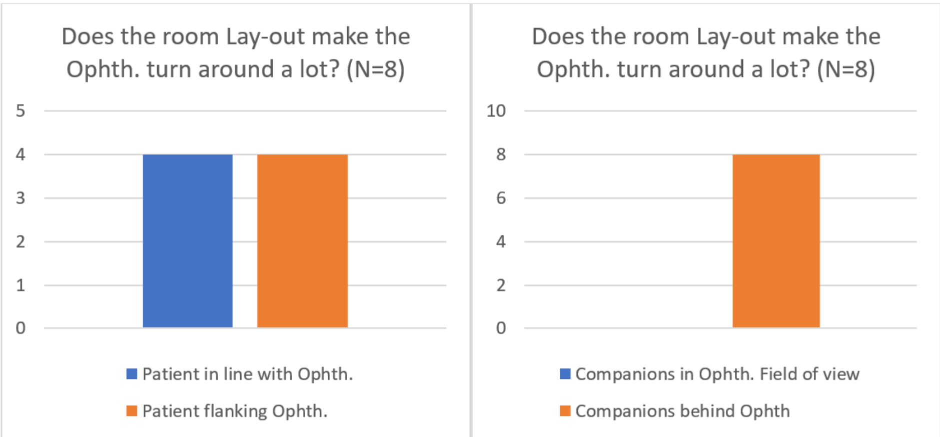


Figure 3 5: Result graphs for Observational prompt 2

Observational prompt 3: Is the equipment (slit lamp) adjusted for good posture of the doctor?
8 out of the 14 Ophthalmologists observed have their equipment set at a height that causes suboptimal spinal posture, either bending down, or overextending. Additionally, height differences between ophthalmologist and patient sometimes require the doctor to use an indirect ophthalmoscope, instead of a slit lamp, to examine the eyes.

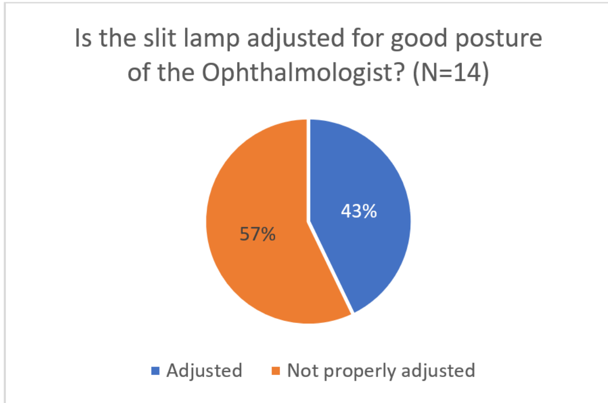


Figure 3 6: Result graph for Observational prompt 3

Observational prompt 4: Does the doctor adjust the slit lamp table at the beginning of the day? Are further adjustments made throughout the day? For what reason?
12 out of the 14 Ophthalmologists make no conscious habit out of properly adjusting the table once in the morning and keeping it constant throughout the day. They instead make adjustments to accommodate patients.

3.6 Full Results

Research Phase

Observational prompt 6: How do they use the separate lens during retinal exams? Where do they rest their arm and hand? Is the lens and/or the elbow rest passed from hand to hand?
All Ophthalmologists rest their elbow during retinal exams. In 11 out of 14 cases, this is on a foam pad. In 2 cases it is an improvised elbow rest as no foam pad is present. 1 ophthalmologist rests their elbow on the table, as their arms are long enough to not need a pad.

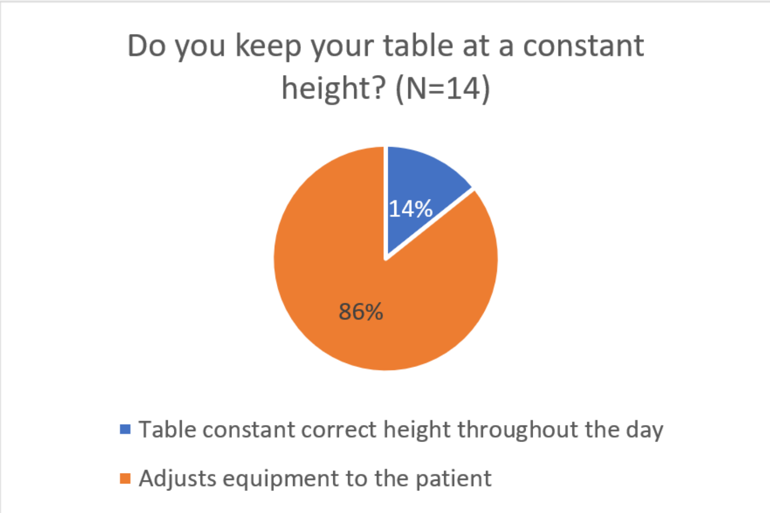


Figure 3 8: Result graph for Observational prompt 4

3.6.2 Results – Interviews

This paragraph contains the abridged list of results from the interviews.

Question 1: Do you have any lasting physical complaints?
11 out of the 14 Ophthalmologists interviewed currently have work-related musculoskeletal injuries (WMIs) in the back, shoulders and/or neck. 3 have WMIs in the hands and/or wrists, while 1 has a WMI in the elbow. This is illustrated in the graph below. 15 WMIs were reported, as some doctors had multiple complaints.

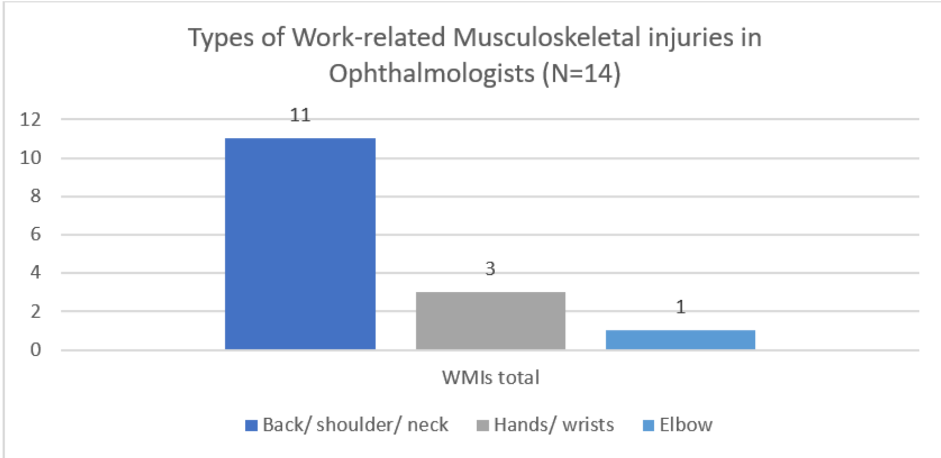


Figure 3 10: Result graph for Interview Question 1, Types of WMIs among Ophthalmologists

Question 2: Are these related to your work, and/or do you see a connection between your work and these problems?
11 out of the 14 Ophthalmologists agree that the complaints are tied to the work.

3.6 Full Results

Research Phase

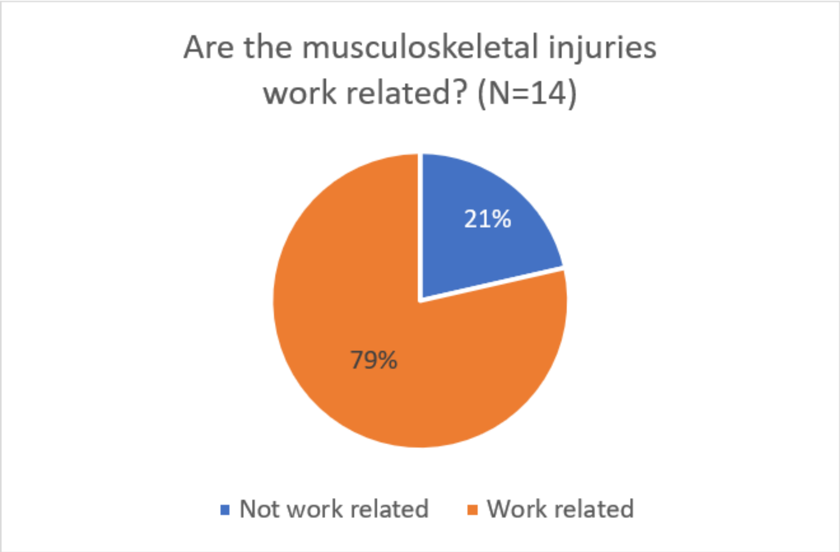


Figure 3 11: Result graph for Interview Question 2

Question 4: What do you think is the cause of these problems? Or what is the biggest cause?
Ophthalmologists interviewed mention the following points as causes for work-related musculoskeletal injuries
a.) Giving priority to patient satisfaction and neglecting personal ergonomics in the process
b.) Inability to adjust equipment to height differences between patient and doctor
c.) Awkward posture during retinal exams

Question 7: Is the equipment properly adjusted to you right now? When do you adjust the slit lamp and surrounding equipment? For what reason?

3 out of 6 respondents that were asked this question are unsure of how to best adjust the equipment and their posture properly. 2 do not adjust as they have not complaints. 2 mention that it takes a long time to properly adjust the equipment

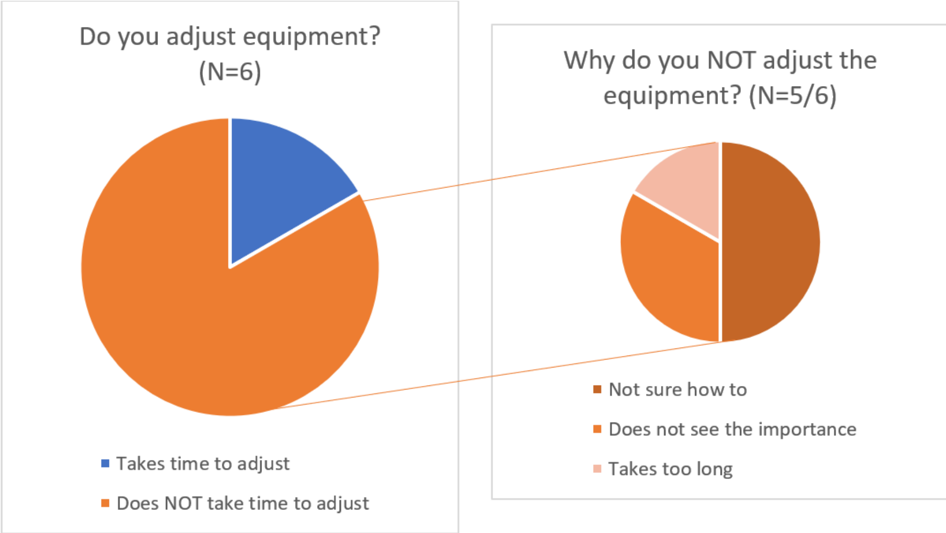


Figure 3 12: Result graph for Interview Question 7

3.6 Full Results

Research Phase

Question 7b: Do you adjust the slit lamp and other equipment more to your own comfort or the patient's?
5 out of 7 Ophthalmologists that answered this question do not adjust the equipment to themselves, but more to the patient.

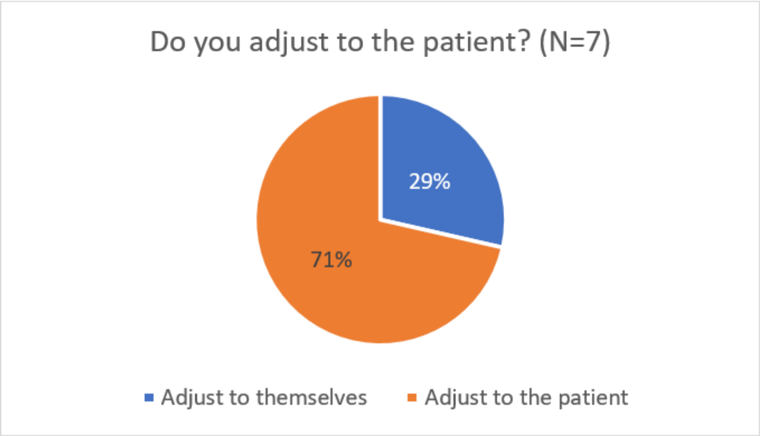


Figure 3 13: Result graph for Interview Question 7b

These results were compiled, as shown in Appendix 11, and used in the next sub-chapter to answer the research questions.

3.7 Conclusions

Research Phase

In this sub-chapter, conclusions are drawn from the research results, to answers the research questions from sub-chapter 3.2.

1. Which work-related physical complaints are most common among Ophthalmologists?

Contrary to my expectations (sub-chapter 2.4), **back, neck and shoulder pains are most common**. Some Ophthalmologists also experience wrist and hand pains, but these are the minority.

2. What are the work-related risk factors that contribute to physical complaints?

a.) What physical workplace properties contribute to the complaints?

I stated in my expectations that the small adjustment knobs and levers, and **insufficient adjustment possibilities on the slit lamp contribute to the development of MSIs for Ophthalmologists.**

Injuries being much more common in the back, shoulders, and neck, as opposed to in the hands and wrists, indicates that the lack of equipment adjustability for ergonomic usage, is a bigger problem than the small adjustment knobs and levers to make said adjustments. This includes:

- Inability to accommodate for height difference between doctor and patient in a mutually comfortable manner.
- Necessity to strain the arm and shoulders during retinal exams due to separate lens.
- Necessity to strain the arm and shoulders using indirect ophthalmoscope for patients in wheelchairs and children.
- Many room lay-outs put the patient perpendicular to and/or flanking the ophthalmologist. This makes the doctor twist their spine to talk to them.

b.) What work-related behavioural patterns contribute to the complaints?

I stated in my expectations that Ophthalmologists work in suboptimal ways, concerning their own health and well-being, to thus meet the high work pressure in their profession, prioritising productivity and patient satisfaction over their own health and wellbeing. Concluding from the research, this neglect of personal health is not only due to high work pressure and prioritisation of patient satisfaction, it is also due to a combination of social norms and physical properties of the workspace. One important aspect is the social norm of facing someone when speaking to them, combined with the aforementioned common layout in ophthalmology rooms, where **the patient is perpendicular to and/or flanking the ophthalmologist, making the doctor twist their spine to talk to them.**

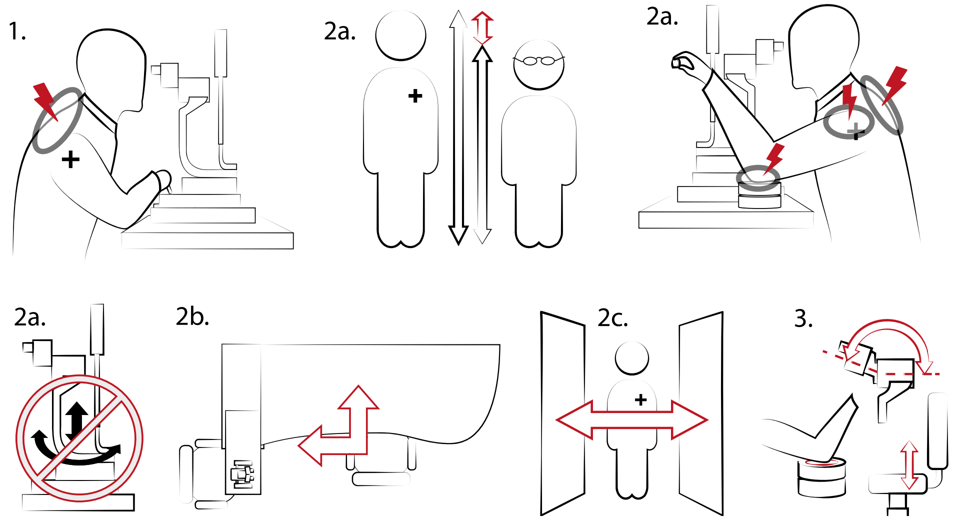


Figure 3 14: Icons representing research conclusions

c.) What work-related logistical circumstances contribute to the complaints?

I stated in my expectations that unclear advice and suboptimal support in terms of ergonomic working from medical institutions contributes to the development of MSDs for Ophthalmologists.

This is indeed part of the problem, with ergonomic support and advice being sparing, divisive, or often absent entirely. Additionally, Ophthalmologists often have to switch to different rooms per, and during the day and as many

3.7 Conclusions

Research Phase

work across locations and institutions, they work in different rooms regularly. This reduces motivation to personally adjust the equipment every morning or whenever they switch rooms.

3. What measures are Ophthalmologists currently taking to prevent or reduce physical complaints?

As expected, many Ophthalmologists say that exercise is important to prevent and/or reduce musculoskeletal Injuries. This is supported by Shelerud (2006) saying, 'The importance of physical fitness and spine support muscle fitness is believed to protect against future occurrences [of occupational low back pain]'. Furthermore, solutions that are currently available, to improve ergonomic working comfort are elbow rests, angle offsets for the eyepiece and height adjustable chairs, patient-chairs, and tables.

4. What is the stance of healthcare institutions as to the ergonomic working conditions of Ophthalmologists, and what measures are being taken to protect them?

Support from medical institutions to prevent or reduce musculoskeletal Injuries in the workforce appears limited. Within the scope of this research, no overarching, concrete framework was observed to protect long-term health for Ophthalmologists. A respected advice document provided by NOG, called The Ophthalmology Standard Practice does exist containing norms and descriptions of the ideal working conditions for Dutch ophthalmology practices. This includes specifications like room sizes, expected activities of support staff, and equipment lists. Sparing emphasis is currently put on ergonomic working conditions. Lastly, training on proper posture and long-term work-related well-being during the ophthalmological specialisation education is similarly sparing.

Institutional attitudes towards the problem of MSDs among Ophthalmologists is not a problem to be solved within this project, it is however an important context factor to be aware of.

With these conclusions I move on to the next phase of the project. The high prevalence of work related back, neck and shoulder pains (sub-Question 1) forms a focus point for the design phase, as I attempt to design a solution to reduce these. The physical workplace properties that contribute to physical complaints (sub-Q 2a) are highly influential in the ideation stage as these are the physical problem spaces that design proposals can pose a solutions to. The behavioural patterns (sub-Q 2b) and logistical circumstances (sub-Q 2c) that contribute to the physical complaints, as well as the institutional stance towards ergonomic working conditions (sub-Q 4) are important context factors for the design, and are also used later, at the end of the report, to formulate recommendations to the ophthalmic sector for improvements to the current work place. The measures Ophthalmologists are currently taking to prevent or reduce physical complaints (sub-Q 3), form context factors to the project and give context on what equipment options are currently available for ergonomic working.

3.8 Problem spaces

Research Phase

Based on the research, **I deduced two problem spaces to design for in the next phase of the project.** I started by distilling the results into underlying sub-problems. I categorised these by the three categories of risk factors contributing to physical complaints, that I identified for my research sub-question: physical, logistical and behavioural. The physical sub-problems were further grouped until they formed the 2 main problem spaces for this project.

To read more about the steps from research to problem spaces, see Appendix 13.

3.8.1 Problem space 1: Position of Ophthalmologist, Patient and Equipment

Ophthalmic equipment doesn't allow an ophthalmologist to work in a comfortable and healthy manner at the moment (Results 2.3, 3.1, 3.2 and 3.3). Many of the conclusions home in on the fact that, when the patient is comfortable sitting behind the slit lamp, the ophthalmologist is not, and is damaging their long-term health; and when the ophthalmologist is comfortable, the patient is not, which in turn is bad for patient satisfaction. Within this problem space, I aim to design a solution that allows both Ophthalmologists and patients, to be comfortable during the ophthalmic examination, while still allowing the ophthalmologist to examine the eyes as usual.

As Venkatesh a Kumar (2017) says, 'minimal modifications in the instrumentation like adjustments in the height of the slit-lamp, operating table and/or microscope eyepieces to maintain the neck and back in a neutral position to avoid unnecessary extension or flexion is necessary to bring down the prevalence of back pain'. The same research states awkward posture as a cause for developing back pain among Ophthalmologists.

3.8.2 Problem space 2: Positioning of the retinal lens

Retinal exams, as they are currently performed, pose significant adverse health effects (Results 4.1, 4.2 and 4.3). As Kent (2011) states, the elbow is 'not designed for weight bearing; it's designed to be a hinge'. Consistently leaning on it, as Ophthalmologists do for retinal exams, can cause numbness, tingling and weakness in the hands. Additionally, holding up the arm for extended periods of time can lead to shoulder disorders or persistent severe pain (Kozak et al., 2019).

By removing the need to hover the arm or part of the arm during retinal exams, pressure on the shoulder joint, upper back and elbow is reduced (Kozak et al., 2019). Additionally, pressure on the elbow is reduced as the ophthalmologist no longer needs to lean on it (Kent, 2011). Both of these reduce long-term stress related injuries.

These two problem spaces form the basis for ideation, the starting point of the subsequent design phase.

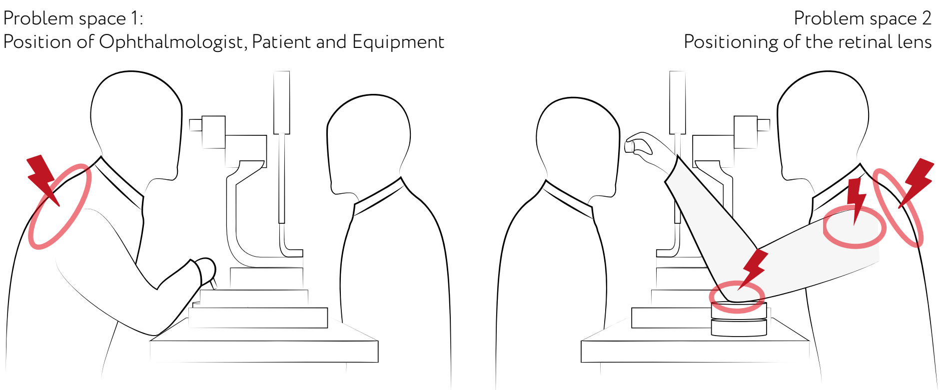


Figure 3 15: The 2 Problem Spaces, that resulted from my research. I took these into the design phase, to develop my concept

3.9 Discussion

Research Phase

The Ophthalmologists, contacted for this study are employed at various types of medical institutions. There has however been an unintentional emphasis on hospitals (8/14) over the other two types, independent treatment centre (3/14) and university medical centre (3/14). While a higher amount of back/neck/shoulder complaints were observed in Ophthalmologists working in hospitals, than in other institution types, ophthalmologist working in hospitals were also the most numerous in the research population. This correlation can therefore likely be ascribed to this respondent discrepancy, but further research could provide more conclusive evidence to this.

The greatest change in personal perspective, brought about by this research, has been the higher prevalence of spinal injuries over injuries in the hands and wrists. This finding is reflected in the design directions I continued with.

The next chapter will describe the design phase of this project.

Design Phase.

The aim of this phase is to determine how the problem described in the previous chapter can be solved; and to develop this solution into an embodied concept design.

Chapter 4.
31. pages

4.1 Background & Design goal

Design Phase

The project goal is improving Ophthalmologists' work-related well-being, the research goal was to find out what is currently the problem and what is the cause of this. The design goal for this next phase, is to determine how the problem described in the previous chapter can be solved; and to develop this solution into an embodied concept design. The design goal of this phase is summarised in the question below.

What equipment redesign or rearrangement, can best reduce work-related musculoskeletal injuries in Ophthalmologists when working with a slit lamp?

This chapter describes how I answered this question.

4.2 Requirements and preferences

To be able to judge ideas and concepts in this phase, a framework is developed to assess them. By establishing a list of requirements for the concept to meet, it can be more objectively argued to be of value to the context.

The list below, includes the most important requirements. The full list is included in Appendix 12.

1. The design concept improves the well-being of Ophthalmologists by improving one or multiple aspects of the physical ergonomics of their daily activities in the outpatient clinic
2. The experience for patients being treated, diagnosed or otherwise interacted with, through the use of the new concept by the ophthalmologist, is equal or better than currently
3. The concept fits within the context of Dutch Ophthalmology institutions and the ophthalmic outpatient clinic in terms of measurements, visual characteristics and auditory experience
4. The concept meets the expected requirements of an industrially produced product
5. The concept is designed in such a way that the users feel naturally inclined to incorporate it into their routine.
6. The concept provides the same basic functionalities as the current alternative

These requirements and preferences may be referred to henceforth in the rest of the report as (Req. [number]), and (Pref. [number]), and are used later to assess the initial designs using Harris Profiles.

4.3 Ideation: Problem Spaces

Design Phase

4.3.1 Current & Envisioned scenarios

I set out after the research phase with 2 problem spaces to design for.

The first problem space is Position of Ophthalmologist, Patient and Equipment.
The current usual scenario before starting examination with a slit lamp is:
1. The patient sits down comfortably
2. The ophthalmologist positions the equipment accordingly
3. The ophthalmologist adapts to where the slit lamp ends up, often being uncomfortable

The current optimal scenario before starting examination with a slit lamp is:
1. The ophthalmologist sits down comfortably
2. The ophthalmologist positions the equipment accordingly
3. The patient adapts to where the slit lamp ends up. Possibly being uncomfortable for the short duration of the examination

The New scenario would be:
1. Both the ophthalmologist and the patient sit down comfortably
2. The equipment adapts/is adapted to bring the image of the patient's eye to the ophthalmologist, without impacting posture of either

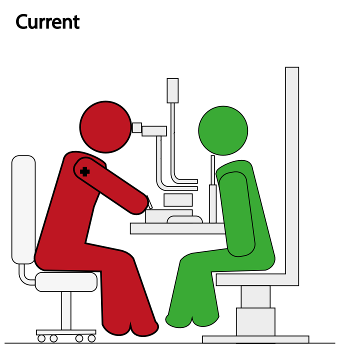


Figure 4 1: Three scenarios for 1st problem space: Current (Ophth. uncomfortable, patient comfortable), current optimal (Ophth. comfortable, patient uncomfortable), and envisioned scenario (both comfortable) within the first problem space: Position of Ophthalmologist, Patient and Equipment.

Translating this problem space to a design direction, this will embody an equipment focussed rearrangement of the relationship between the three actors in the context: 1. Ophthalmologist, 2. Patient and 3. Ophthalmic equipment.

The second problem space is Positioning of the retinal lens.
The current sub-optimal scenario when doing a retinal exam is:
[Ophthalmologist and patient sit across the slit lamp]
1. Ophthalmologist picks up separate lens and hovers their arm in the air, unsupported, if an elbow rest is absent (or doctor has to improvise on the spot). If it is present, it can be of a suboptimal height for the doctor, causing bad posture.
2. Places lens between slit lamp and patient eye, possibly resting hand against chin rest or patient face
3. [ophthalmoscope examination]

The current optimal scenario when doing a retinal exam is:
1. Ophthalmologist picks up separate lens, places elbow rest in position, places elbow on elbow rest, places lens between slit lamp and patient eye, possibly resting hand against chin rest or patient face

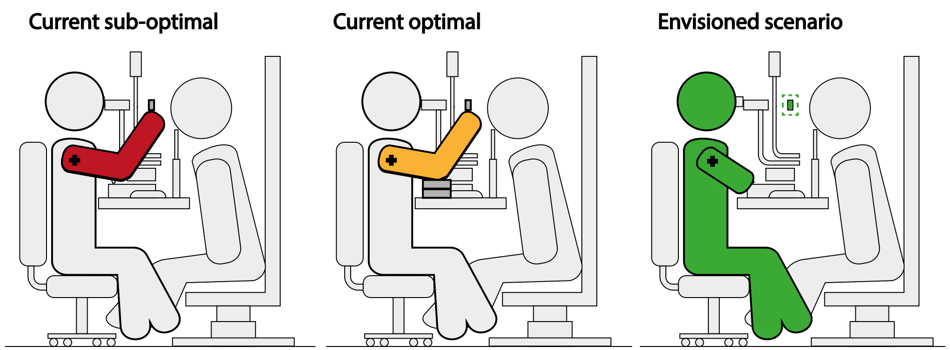


Figure 4 2: Three scenarios for 2nd problem space: Current sub-optimal (Ophth. arm unsupported), current optimal (Ophth. arm partially supported), and envisioned scenario (arm in relaxed position, lens attached) within the second problem space: Positioning of the retinal lens

4.3 Ideation: Design Directions

Design Phase

2. [ophthalmoscope examination]
3. Ophthalmologist puts lens down

The New scenario would be:
1. Lens is attached, no longer requiring ophthalmologist to hold it up
2. Ophthalmologist arm is no longer stretched out or up
3. Wrist in neutral position
4. Shoulder is relaxed

After an initial stage of ideation within these two directions, I formulated a further division into 4 sub-directions. Directions A and B correspond to Problem space 1: Position of Ophthalmologist, Patient and Equipment, Directions C and D correspond to Problem space 2: Positioning of the retinal lens.

Figure 4 3: Path of the light/image redirected by mirrors inside a Slit Lamp (the green arrow)

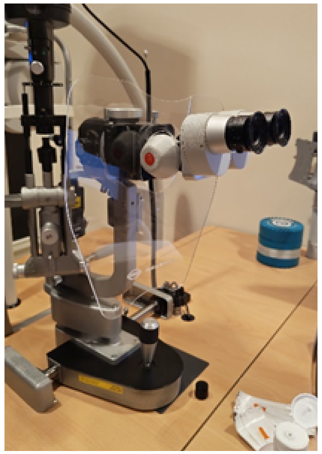


Figure 4 4: A lesser used model of Slit lamp with a rotatable (up and down) eyepiece

4.3.2 Direction A: Redirecting the Picture

The first sub-direction is Redirecting the picture. This means comfort during examination for both doctor and patient, regardless of height, is facilitated by the equipment. It does so by redirecting the image of the patient's eye to the doctor. This image is already redirected to some degree in the existing equipment, as shown by the path the light takes in figure 4.3, left. Extending this redirection therefore, is a feasible proposal.

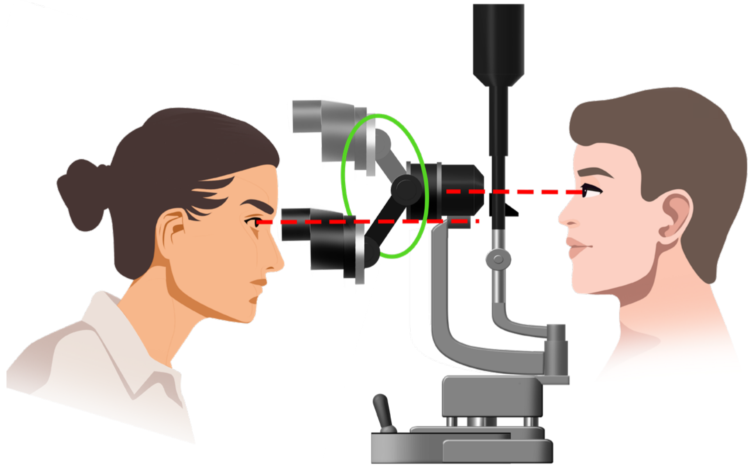


Figure 4 5: One way to realise Direction A: Redirecting the Picture

One way to realise this is shown above, in which the redesigned part is encircled in green, with the different eye heights in red. The challenge for this sub-direction, is ensuring a quality image. As mentioned during the interviews, the more you redirect the bundle of light that forms an image, by means of mirrors, lenses, or electronic equipment, the more the observed image is distorted. This is due to the inherent imperfections of the materials conveying it. This is one of the reasons why a slit lamp such as the one shown in Figure 4.4 on the left, with more adjustability, is not used as much as the more static type: the image quality is deemed inferior.

4.3 Ideation: Design Directions

Design Phase

4.3.3 Direction B: Aligning Doctor and Patient

The second sub-direction is Aligning Doctor and Patient. This means comfort for both ophthalmologist and patient, during examination, is facilitated by physically rearranging the two parties in the space, to align their lines of sight (shown in Figure 4.6, below). The challenge for this sub-direction is the fact that the patient and/or the doctor has to physically move or be moved to align the eyes. Doing so in a way that is both comfortable and fast is crucial. The advantage this sub-direction has over the first however, is that the image does not need to be redirected, preserving image quality.

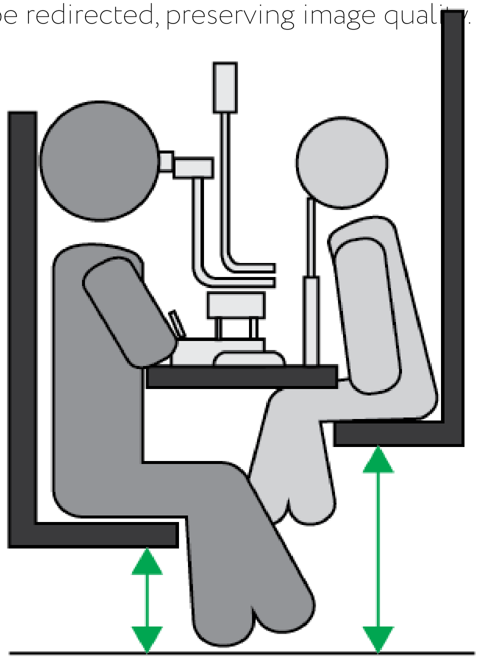


Figure 4 6: One way to realise Direction B: Aligning Doctor and Patient

Sub-directions C and D are centred around the retinal lens, used by the ophthalmologist during retinal exam. In these check-ups, the doctor holds the lens free-hand, between the slit lamp and the patient's eye to adapt the magnification and examine different parts of the retina by moving the lens slightly. Both of the next sub-directions are based on the need for a stable retinal lens, which is not held by the doctor. By attaching the lens to another stable factor, it removes the need for the ophthalmologist to strain their arm in holding the lens up. This strain, as described in the research chapter, has been connected to the development of MSIs.

4.3.4 Direction C: Attaching Retinal lens to Slit lamp

The third sub-direction is attaching retinal lens to slit lamp. This means the need to hover the arm or part of the arm during retinal exams is removed by attaching the lens to the slit lamp. Figure 4.7 below shows one way to achieve this, as the lens (in blue) could be attached to an arm on the slit lamp. The challenge for this sub-direction, as well as the next one, is the distance and position of the lens, relative to the patient eye. This positioning needs to be very precise, to get a clear image. This is currently done by hand, guided by years of experience, but if the lens is attached, the minute positioning needs to be facilitated in another way.

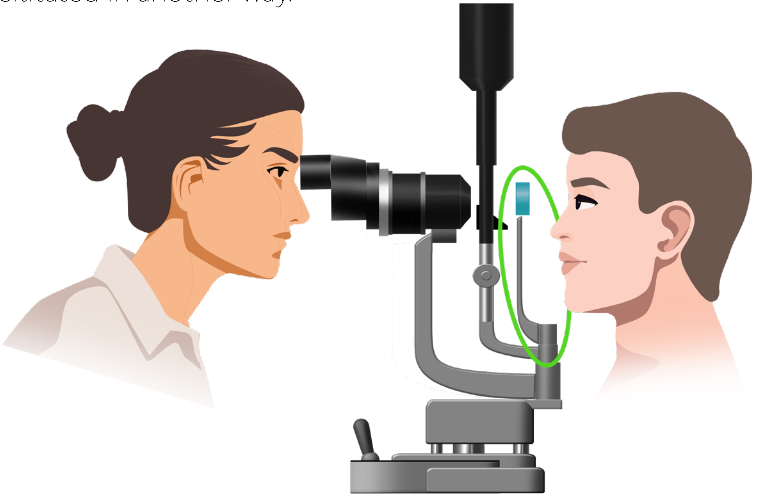


Figure 4 7: One way to realise Direction C: Attaching Retinal lens to Slit lamp

4.3 Ideation: Design Decisions

Design Phase

4.3.5 Direction D: Attaching retinal lens to Patient

The fourth sub-direction is attaching retinal lens to Patient. This means the need to hover the arm or part of the arm during retinal exams is removed by attaching the lens to the other stable actor in the context, the patient. Figure 4.8 below shows one way to achieve this, as the lens (in blue) could for instance be attached to glasses, worn by the patient.

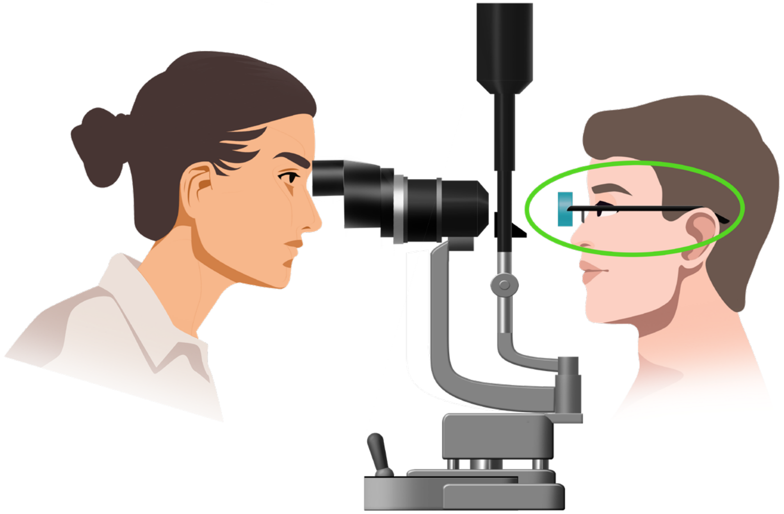


Figure 4 8: One way to realise Direction D: Attaching retinal lens to Patient

The advantage to this sub-direction, is the distance from lens to patient could be manipulated very precisely, as the distance is reduced to one factor, instead of the current two: moving lens and moving patient. The challenge for this sub-direction is to ensure patient comfort and to ensure the patient's head is actually stable

4.3.6 Decision making – Harris profiles

After further ideation, and reconsideration of my research, I made the decision to drop direction D. When reconsidering the research, many Ophthalmologists ask the patient to keep their head steady during examination. The patient isn't the stable actor you want for the lens. I therefore only continued ideation for sub-directions A, B & C.

After a next ideation loop, including lo-fi prototyping to understand the effect of different solutions and ideas on the user's posture (figure 4.9, right), **a well-informed decision was made on what solution to develop further, using Harris profiles**. In this decision-making method, a number of solutions are judged based on a set of criteria, on a 4-point scale, -2 being worst, +2 being best. I took the criteria from the previously established list of requirements, only using the requirements relevant at this level of detail. The criteria used are, Physical ergonomics improvement (1), Patient experience (2), Intuitive use (5.1), Comfort of use (5.3), Time to use (5.4) and extrapolation of Purchase cost (7). When determining the results of the Harris profiles, idea 10: Height Matcher is clearly the best choice. Table 4.1 on the right shows the Harris profile for the chosen concept.

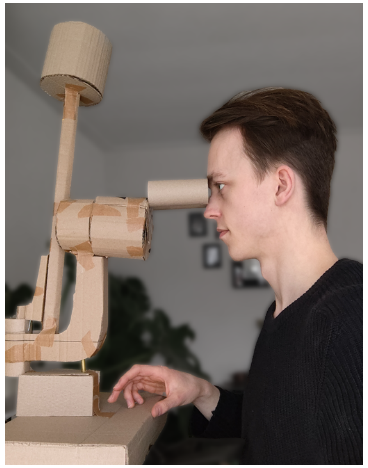


Figure 4 9: Lo-Fi Prototype of a slit lamp, made to understand the effect of different design ideas on the user's posture

Table 4 1: Harris Profile for chosen concept: Height Matcher. In a Harris profile, a concept is scored on several criteria, ordered from most important (top) to least important (bottom). for this concept, all scores are positive, with the exception of production cost at the bottom

10. Height Matcher			
-2	-1	+1	+2

4.3 Ideation: Chosen Concept

Design Phase

4.3.7 Conclusion - Chosen concept: Height Matcher

The chosen solution is a redesign of the ophthalmic examination unit with ergonomics as a priority. It integrates the patient chair and slit lamp table into a single unit and upgrades them in several ways to improve both the ophthalmologist's and the patient's posture during examination. It strongly reduces the risk of long term health effects and has a high comfort of use. It furthermore scores positive on nearly all other categories. The only negative is purchase cost which, with its higher complexity than the current unit, is likely to be high. It would also be a full replacement of the examination unit, except for the slit lamp. This high purchase cost is something to keep in mind for future development. The decision making process is described in detail in Appendix 14.

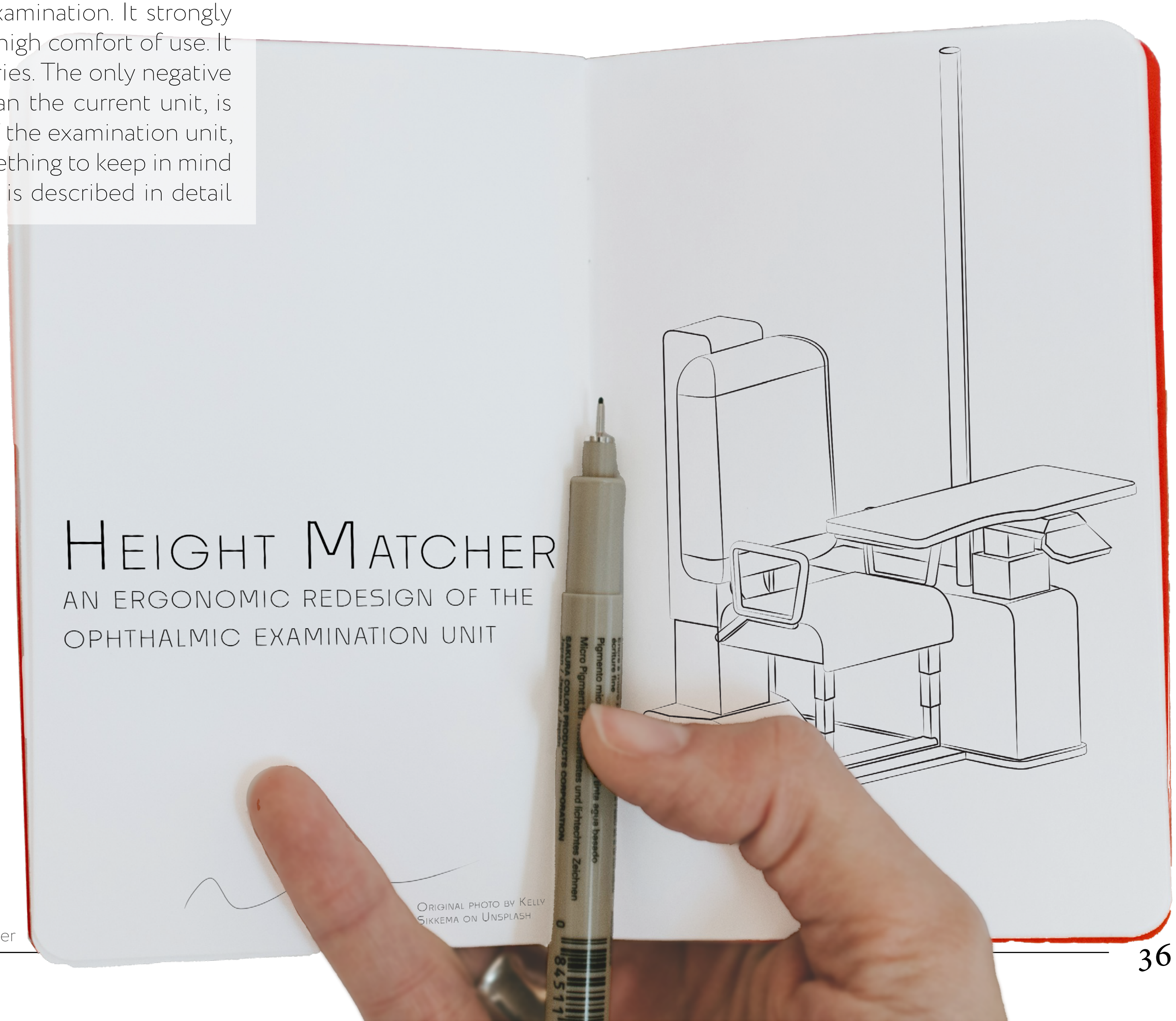


Figure 4.10: Chosen concept: Height Matcher

4.4 Conceptualisation: Detailed concept

Design Phase

In this sub-chapter, I will go into detail, describing the concept's distinct parts and functionalities. **The most important research conclusions driving this concept are:** the most common physical complaints in Ophthalmologists are in the shoulders, back and neck (1.), this is caused by high workload (2.1) and continuously working in different rooms (2.2), which can both cause Ophthalmologists to lose motivation to keep adjusting the equipment to their comfort; the fact that the current equipment is not adaptable enough (2.3) to accommodate patients and Ophthalmologists of different heights (3.3); and the fact that most Ophthalmologists in this situation will choose their patients' comfort over their own (3).

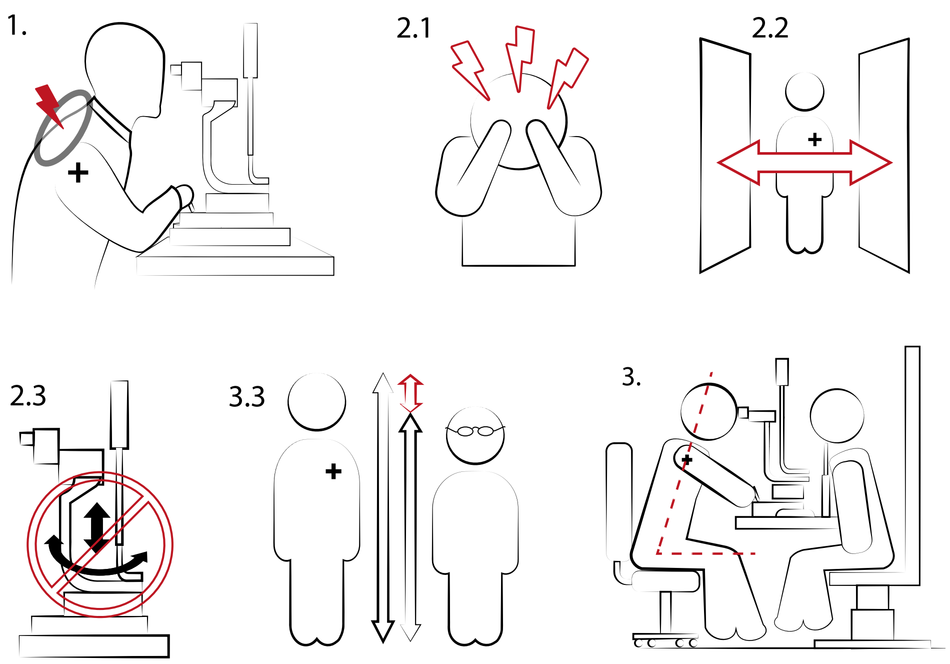


Figure 4 11: Icons representing research conclusions that the concept was built on

In the end, much is possible with the current equipment in terms of ergonomic adjustment, but (I) it is too limited, (II) it takes too long, and (III) it takes too much effort. My concept aims to remedy this by:

I. Extending: More height adjustability with a greater range so that you can always work comfortably, even standing up
- Greater height range: minimum and maximum height settings are further apart

II. Accelerating: Higher responsivity and quicker interaction so that the adjustment is actually made
- Higher responsivity: for instance, less actuator delay, repositioning of parts for shorter radius, etc.
- Quicker interaction: for instance, single button presses have larger effect, buttons grouped/positioned smarter to decrease use time, etc.

III. Simplifying: Clearer and more intuitive controls
- Intuitive: 'when a user is able to understand and use a design immediately—that is, without consciously thinking about how to do it—we describe the design as "intuitive" ' (IDF, 2024).

It is in the above three ways, that the concept improves upon current units.

4.4 Conceptualisation: Detailed concept

Design Phase

4.4.1 New scenario

This concept is a **redesign of the ophthalmic examination unit with ergonomics as a priority**. It integrates the patient chair and slit lamp table into a single unit and upgrades their adjustability in several ways to benefit both doctor and patient. By extending the adjustment range, speeding up the interaction, and simplifying the process, it enables the ophthalmologist to work in an ergonomic posture, seated or even standing up, and also allows the patient to maintain ergonomic posture during examination.

The three parts of the concept: (1) measuring stick, (2) Chair/Table Unit, and (3) Interface, as well as their use scenario, are further elaborated on in the following pages

For more details on the design process that led up to the final concept, see Appendices 15 through 23.

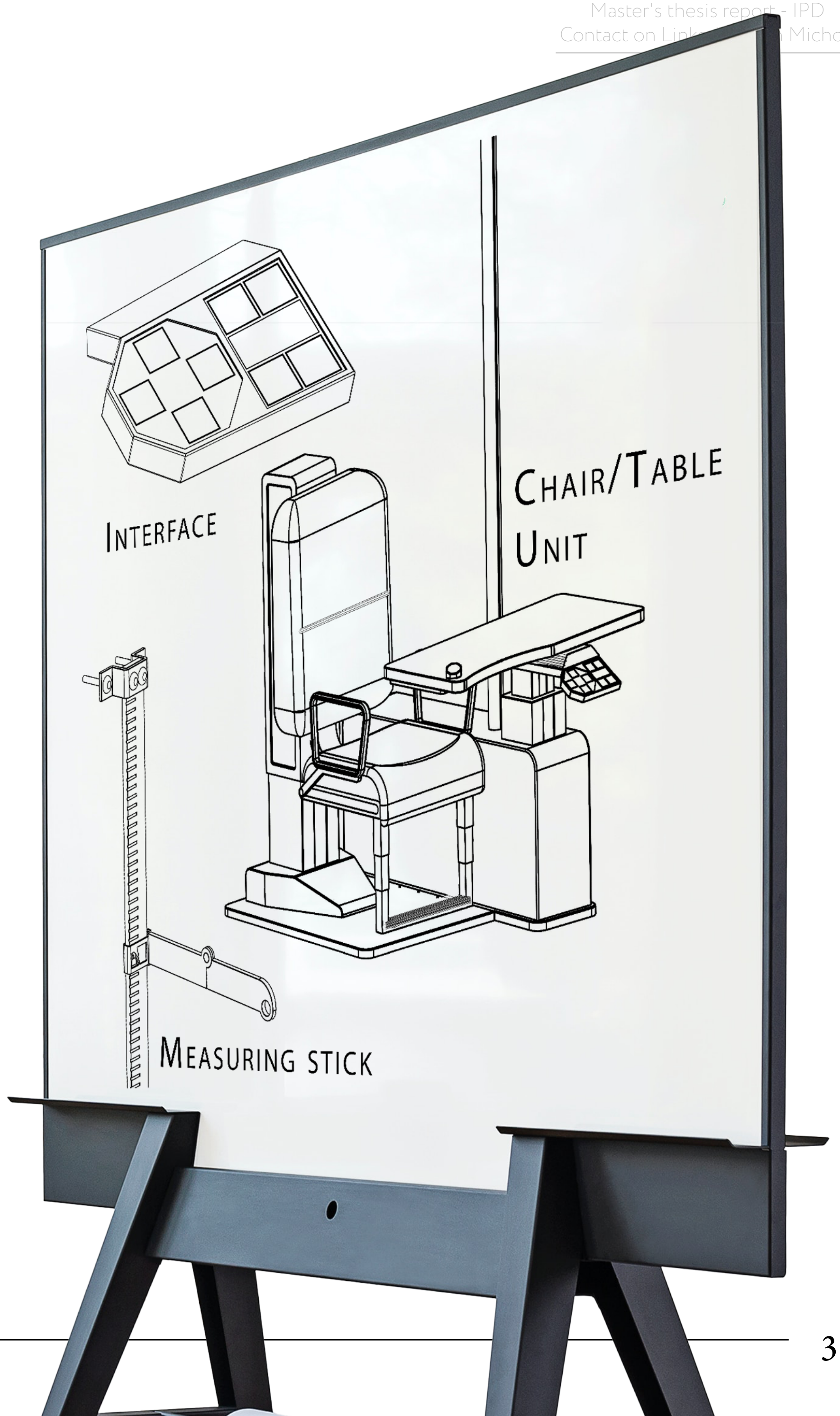


Figure 4 12: The three parts of the concept

4.4 Conceptualisation: Use Scenario

Design Phase

Figure 4.13 below shows **the new scenario, using the design concept**. It shows the interaction when the ophthalmologist chooses to work while standing. It is still possible to work while sitting as well. For this, the ophthalmologist simply skips step 5.2. The dark grey figure represents the ophthalmologist, while objects indicated in blue are parts of the concept being interacted with.

Consequently, the new scenario is minimally intrusive, and requires little adaptation from the ophthalmologist as compared to the current situation. Yet with these adjustments, their posture, and therefore physical health, will be protected throughout their career.

1. The ophthalmologist's eye height is measured when they start in the profession. This is done by a second person, ensuring proper posture and measurement. They measure the sitting and standing eye height by moving the slider along the measuring stick until the ophthalmologist can comfortably look through the eye hole.

2. With the slider staying in place, it is easy to read the corresponding eye height on the rod.

3. When the ophthalmologist goes to work in the outpatient clinic, the two eye heights are dialled into the interface panel.

4. The slit lamp table moves to bring the eyepiece to the ophthalmologist's eye height. This height is not adjusted for the rest of the day, and any adjustments after are to the patient chair.

5. When the patient comes in, the ophthalmologist greets them and asks them to take a seat in the patient chair. They might adjust the chair backwards depending on the patient's proportions (More corpulent patients need more space to sit comfortably behind the table and smaller/shorter people need to go further forward).

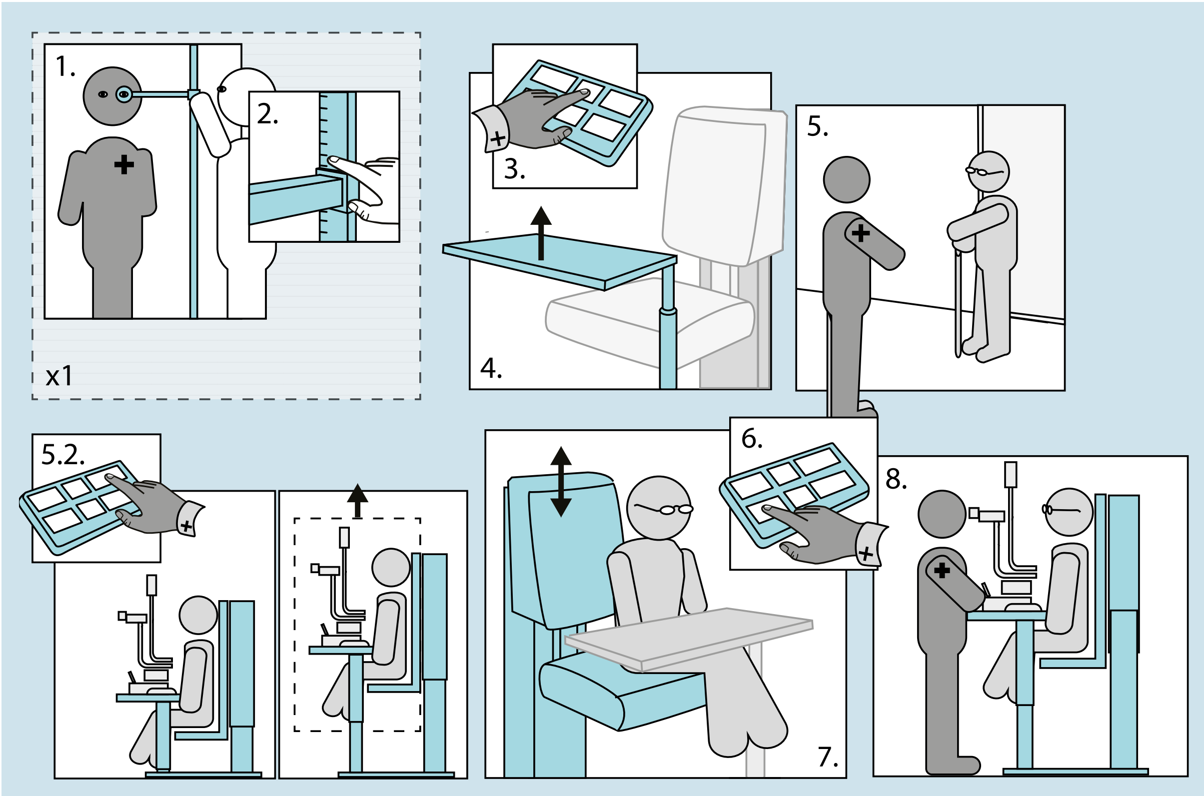


Figure 4 13: New use scenario with the Ophthalmologist standing, examining while sitting is also possible.

5.2 If the ophthalmologist wants to examine the patient in standing position, they press the mode change button, to transition from sitting to standing mode. The patient chair and slit lamp table move up proportionally, to maintain their relative distance, for seamless working.

6. The doctor adjusts the patient's chair further, to line up the patient's eyes with the slit lamp.

7. The patient chair moves up to the correct height and can be finetuned if at all necessary.

8. The doctor examines the patient as usual, with good ergonomic posture for both.

4.4 Conceptualisation: Use Scenario

Design Phase

The main addition is the eye height measuring interaction, which is relatively fast, and will be carried out at the same time as the pupillary distance measurement. A measurement that is already done for starting Ophthalmologists.

While this measurement will only be done once, it remains important to have at least one measuring stick in every clinic, as eye height can vary slightly, depending on the chair the ophthalmologist is sitting on when examining in sitting mode. With the variety of different working chairs that are generally present in different medical institutions (Figure 4.14, right), outpatient clinics and even differing between rooms, it is important to keep the ability for employees to measure their eye height. This also applies if new chairs are introduced for the doctors. Additionally, this proves it is important for the initial eye height measurement to be carried out with the ophthalmologist sitting in their usual working chair. The next paragraph will go into more detail on this.

The design concept consists of three parts, the measuring stick (1), the adapted patient chair (2), and the interface (3). In the following paragraphs I will describe every part in detail.

Figure 4 14: Large variety in Chairs used by Ophthalmologist in medical institutions

4.4 Conceptualisation: Measuring stick

Design Phase

4.4.2 Measuring stick

The first part of this design concept is the measuring stick, shown on the right. The essence of this design is for the interaction to be simple and familiar. It is meant to require the least amount of time and effort from the users. The rod is long enough to allow users of any height, standing or sitting, to measure their eye height quickly and easily. The slider is moved along the rod until the eye hole lines up comfortably with the users eye. The slider can be released, it stays in place and the user can read their eye height on the rod.

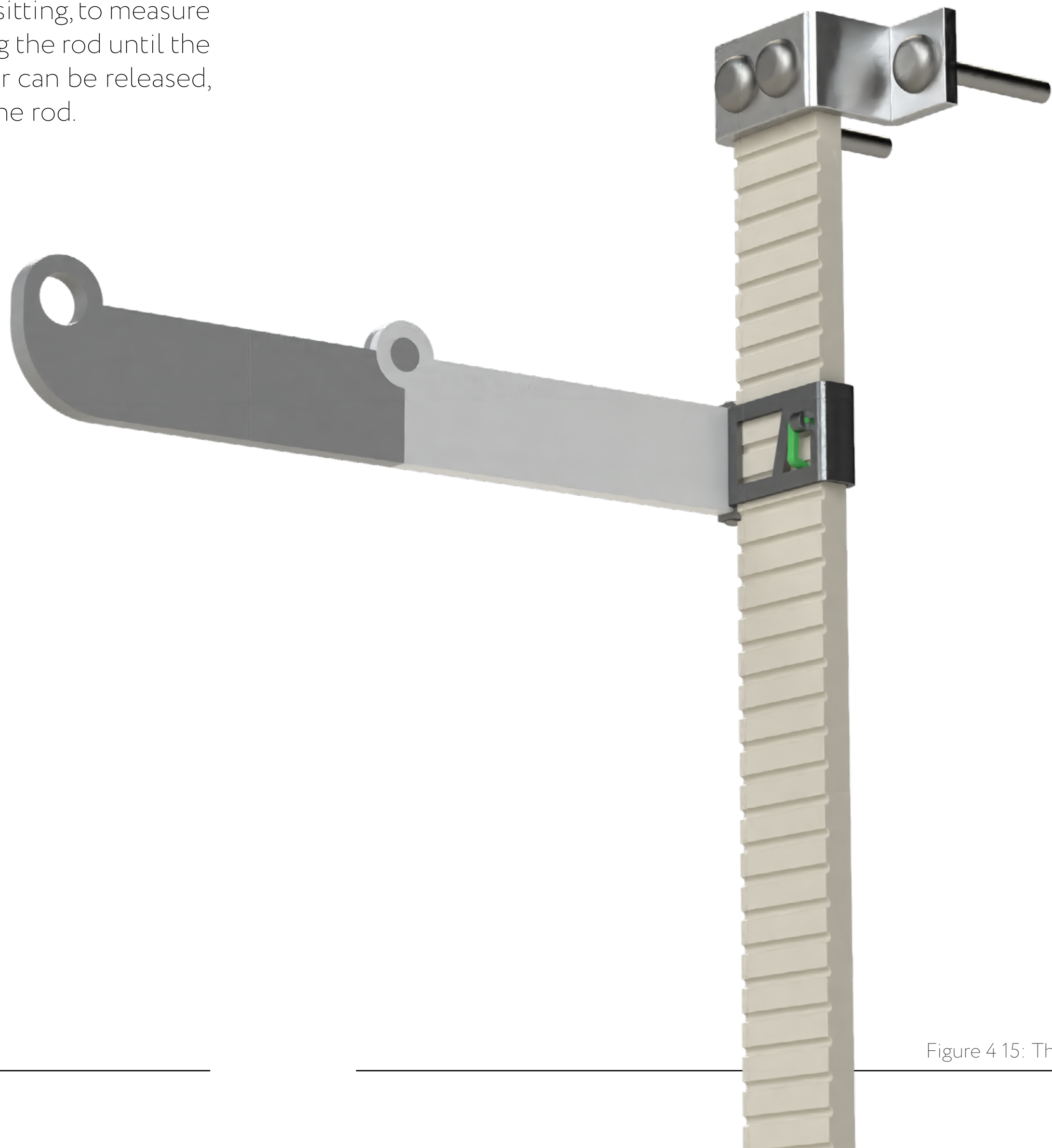


Figure 4 15: The measuring stick

4.4 Conceptualisation: Measuring stick

Design Phase

Currently, when Ophthalmologists enter the field, their pupillary distance (PD) is measured. This is important to use the eyepiece on the slit lamp properly. The pupillary distance is the distance from pupil to pupil, and needs to correspond with the distance between the two lenses on the eyepiece. If this distance is off, it can lead to an unclear image and a headache for the doctor. The eye height measurement will be included in this interaction, to form the least amount of intrusion on the current process. Multiple Ophthalmologists I visited, mentioned this opportunity separately and unprompted. This initial measurement is carried out by a second person, which ensures the doctor is sitting/standing in optimal ergonomic posture during the measurement. This in turn, ensures the measurement is valid and can be used for ergonomic working from then on.

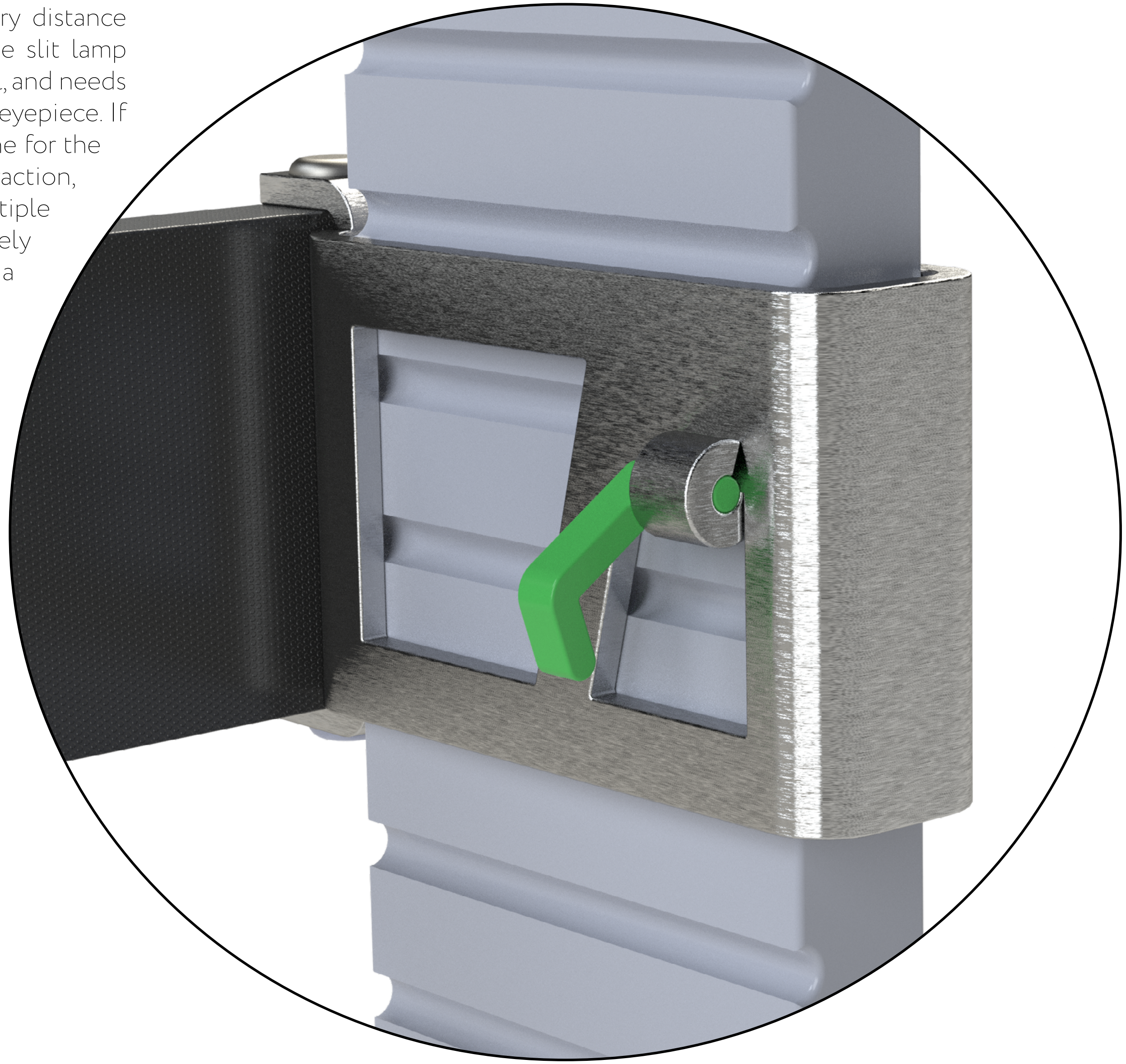


Figure 4 16: Moveable locking pin (green) on measuring slider

4.4 Conceptualisation: Measuring stick

Design Phase

The measuring goes as follows:
The ophthalmologist stands with their shoulder towards the wall. The person carrying out the measurement makes sure the ophthalmologist is standing in proper posture.

1. The measurer unfolds the slider
2. The measurer unlocks the slider by lifting the locking pin (Figure 4.16, previous page),
3. They then move the slider along the length...
4. ...until the eye hole is in line with the ophthalmologist's eye
5. This standing eye height is fine-tuned if necessary and the measurement is read and recorded

This process is repeated with the ophthalmologist sitting down in their regular working chair to get the sitting eye height

The Ophthalmologists I visited, related that every ophthalmologist knows their own pupillary distance (PD) by heart. For them to also remember their sitting and standing eye height is therefore more than feasible. These two known eye heights will be the basis for more ergonomic working.

For more information on the design process that resulted in this part of the concept, see Appendix 16.

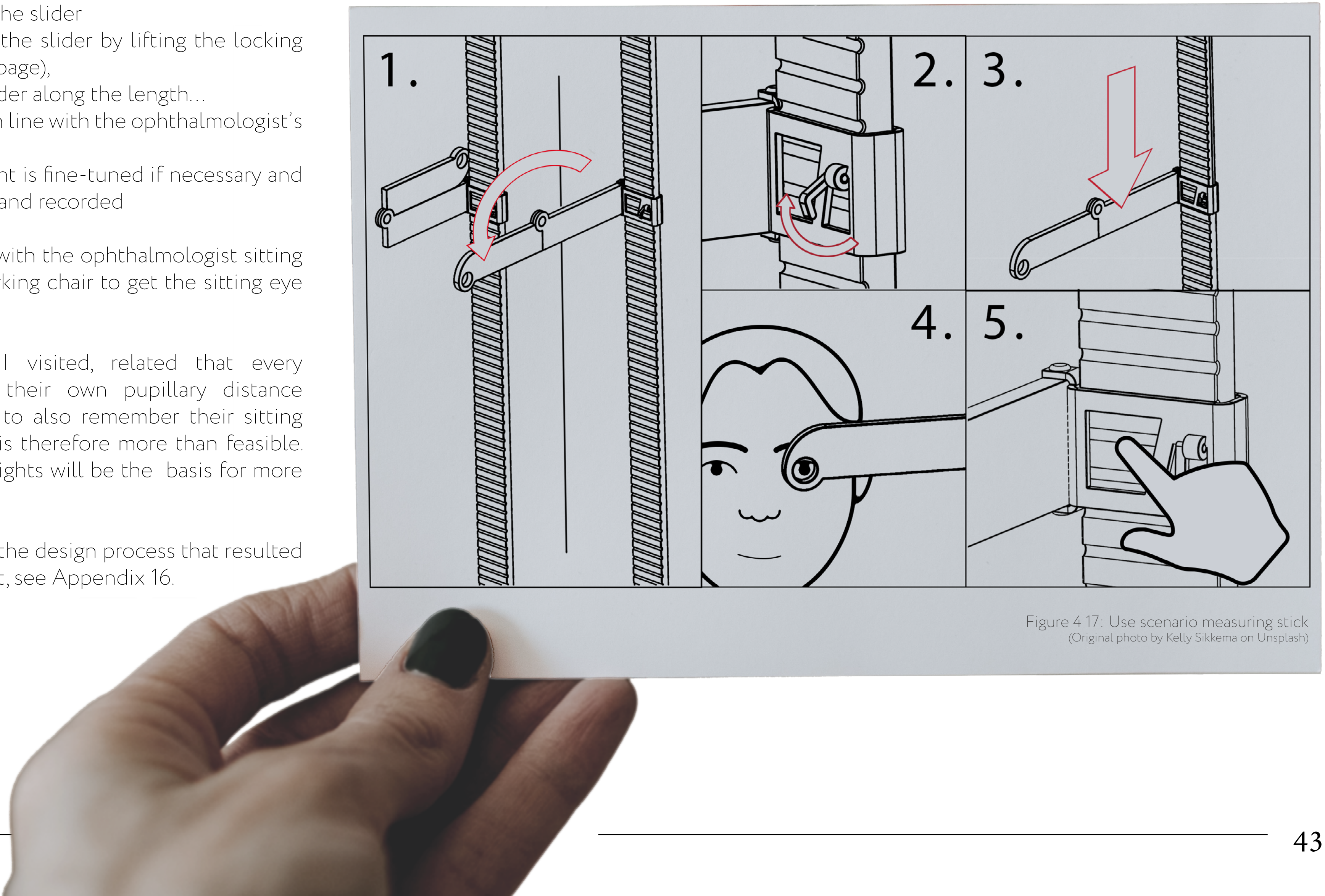


Figure 4 17: Use scenario measuring stick
(Original photo by Kelly Sikkema on Unsplash)

4.4 Conceptualisation: Table/chair unit

Design Phase

4.4.3 Adapted Chair/Table Unit

The second part of this design concept is the adapted Chair/Table Unit, shown in figure 4.19 on the right. This redesign of the ophthalmic examination unit extends the height adjustability range of the patient seat and table. This allows Ophthalmologists to bring patient eyes and the slit lamp lens level with their own eyes, regardless of height differences or physical proportions.

Figure 4.18 below shows the necessary height range to work ergonomically while sitting (blue arrow). While the current units do not allow for this range, the concept goes far beyond, allowing the user to work while standing as well.

This **significantly greater height range** compared to the current units, allows the table to be set anywhere between 561 and 1300mm off the floor. For the chair this is between 283mm and 978mm. The range of the current units meanwhile, is 780-980mm (table) and 500-700mm (chair).

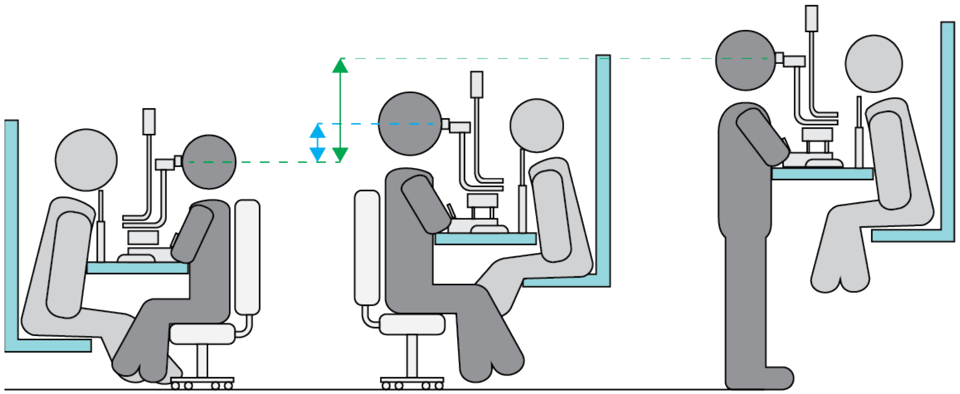


Figure 4 18: Necessary dynamic height range (green), to allow the majority of Ophthalmologists to work ergonomically: 555mm to 1236mm off the ground. (DINED, n.d.) (Further elaborated on in Appendix 8: Clinic equipment measurements)

Figure 4 19: Adapted Chair/Table Unit

4.4 Conceptualisation: Table/chair unit

Design Phase

The extended range allows users to work in an ergonomic manner, even with substantial height differences between ophthalmologist and patient. These often exist with the predominantly older patient demographic.

This extended range is realised **by placing the extending column behind the chair, instead of under it** as it is currently. Through this repositioning, it can be extended, making the range of motion much greater (green arrow in Figure 4.18 on the previous page).

Figure 4 20: The extending column, now behind the chair, instead of under it

4.4 Conceptualisation: Table/chair unit

Design Phase

Safety for the patient while high up, in standing mode, is guaranteed as they are encircled by the backrest, armrests, and the slit lamp table. A safety feature is included, deactivating the table disengage button while in standing mode, so it can never come away while the patient is up.

Figure 4 21: The adapted Unit, disengaged (left), engaged with patient sitting in the chair (middle), and in standing mode

4.4 Conceptualisation: Table/chair unit

Design Phase

Secondly, a **footrest** is added for the patient, so they are supported in standing mode. This is important as unsupported feet can cause compression stresses and an uncomfortable feeling to the sitting person (Huang et al., 2016).

To prevent the patient's feet getting caught under the footrest when moving down, **the footrest has a telescopic construction**, thus collapses when in the lower position. (Blue in figure 4.22, below). This also means the chair can still be lowered sufficiently to facilitate the lower end of its range of motion.

The concept's chair and table move faster than the current alternatives in transitioning from sitting to standing mode. If the chair were to move along its new, greater range of motion with the current speed, it would take almost a full minute (Appendix 8: Clinic equipment measurements). Keeping in mind the short patient visits, increasing this speed is paramount. A slow build-up and fall-off is included to not cause discomfort for the patient (Req. 2).

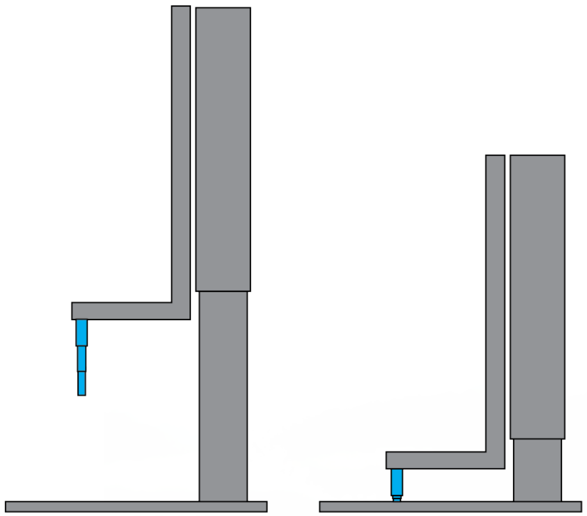


Figure 4 22: Telescopic footrest, to collapse in lower position

Figure 4 23: Collapsable telescopic footrest with a soft support, under the chair

4.4 Conceptualisation: Table/chair unit

Design Phase

This concept improves the ergonomic working condition of Ophthalmologists by facilitating a better, upright posture. This is because Ophthalmologists no longer have to stretch or bend to meet the patient's eyes. It however also **improves the user's posture by reducing spinal twisting during patient visits.** One of the research conclusions states that half of ophthalmic clinic rooms have the patient flanking the ophthalmologist, shown by the left map (figure 4.24, right). When the doctor is flanked, they have to twist to face their patient. Algarni & Alkhaldi (2021) concludes that this regular twisting causes MSDs over time.

The current table units often can't be installed in the ergonomically better in-line direction, as the room is simply too small (top right, Figure 4.24). One of the suppliers at the NOG conference elaborated on this saying, units are simply placed in the room, as best as possible. Rooms are not modified to be ergonomically better (Appendix 21: NOG conference).

The map in the bottom of the figure shows the situation with the concept table/chair unit. Its rotational table motion reduces its total surface area, thus allowing the patient to be placed in line with the Ophthalmologists, instead of perpendicular, as current alternatives often require.

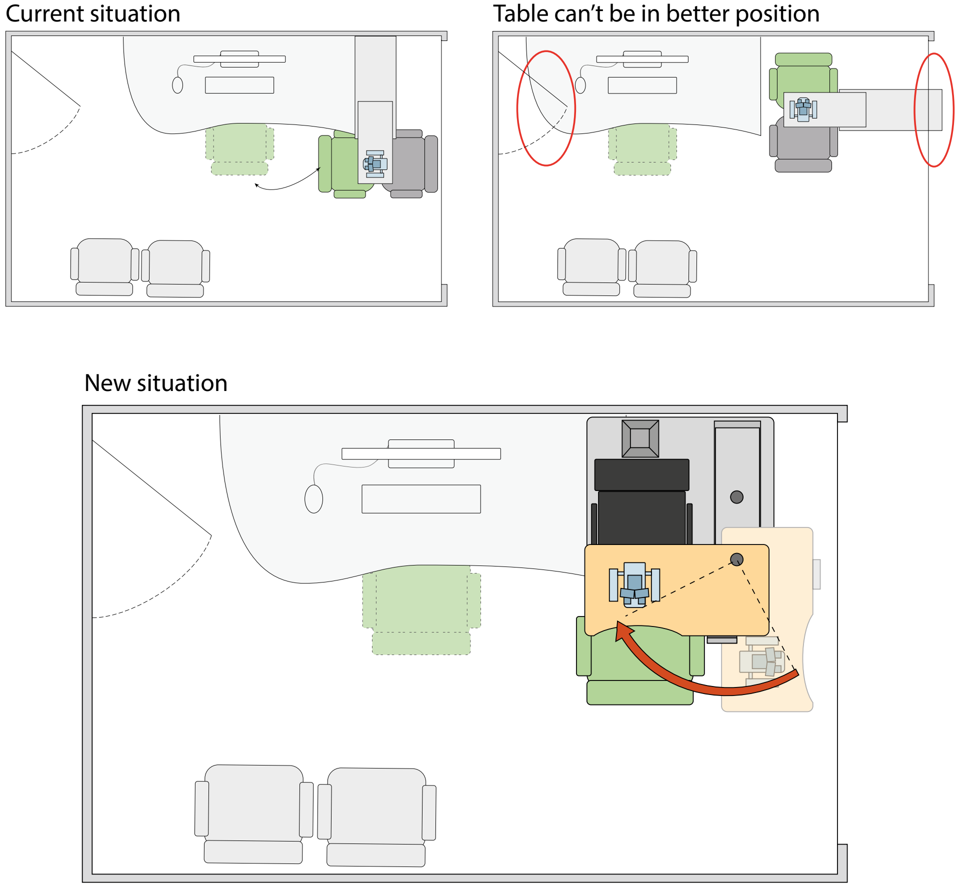


Figure 4 24: Room impracticality, top left shows how patient is often perpendicular to doctor, necessary as room does not allow for the better layout (top right). The concept does allow for the patient to be in line with the doctor (bottom).

4.4 Conceptualisation: Table/chair unit

Design Phase

Another advantage to the concept is that it allows **the examination of wheelchair using patients**, without any additions or reconfigurations. If a patient using a wheelchair is examined by an ophthalmologist currently, the patient either has to be helped to move from their wheelchair into the unit chair, be examined with a hand-held ophthalmoscope, or the ophthalmologist has to drag the unit chair sideways to make room for the wheelchair. All of these options are highly strenuous. The concept needs no such effort, as by leaving the table in the forward position, wheelchair users can be examined seamlessly, as shown below. Examination in the unit chair is still preferred, as examination from the wheelchair negates the height adjustability of the patient, but the feature facilitates the minority of fully wheelchair-bound patients.

Figure 4 25: Concept facilitates wheelchair using patients when table is left in forward position

Ergonomics for the crew assembling and installing the unit was also considered. An earlier version saw the baseplates for the chair and table joined into one large baseplate for the sake of stability and strength. My interview with an industry representative made me realise that, if these two are joined, it is significantly harder to install the unit, or rather, to get it into the room (Appendix 22). For this reason a middle ground was found between stability and practicality, by joining the two during installation in the clinic. This baseplate connection is semi-permanent, with the connection also housing the electrical connectors for the unit's electro mechanical functions. Figure 4.26 below shows the connection.

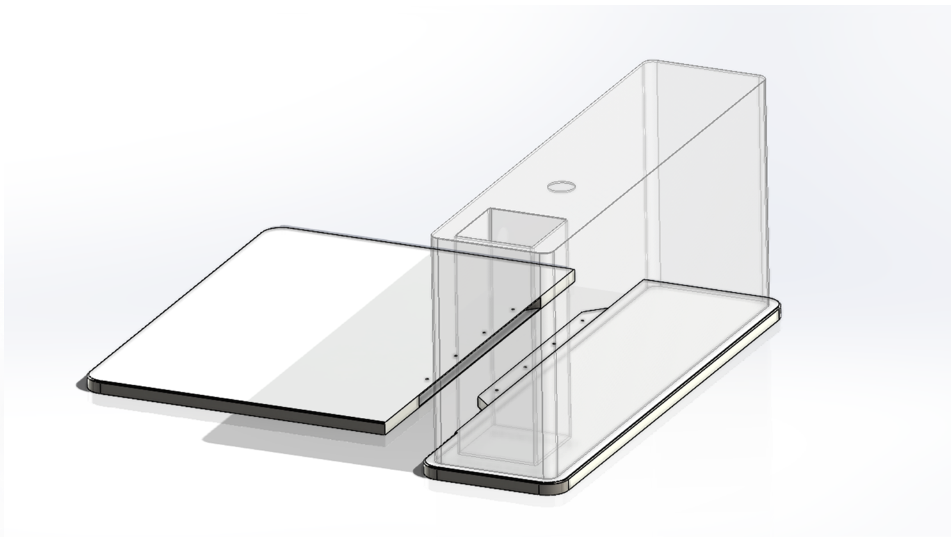


Figure 4 26: Base plate is joined during installation to protect technicians' health and for ease of transport

4.4 Conceptualisation: Table/chair unit

Design Phase

The parts of the adapted Chair/Table Unit are shown below.

1. Posterior column

The chair is fixed to the main column behind the chair

2. Patient chair

The padded chair the patient sits in during the examination visit

3. Arm rests

For patient comfort, as well as safety during standing examination, to prevent them from falling off the chair sideways

4. Collapsible foot rest

Collapsible footrest: For patient comfort, resting their feet during standing examination. It collapses to allow the chair to come down lower

5. Base plate

Separates into two sections that are joined during installation to ease transport

6. Phoropter Pole

Hollow metal pole that facilitates a phoropter

7. Ophthalmic equipment

Slit lamp, secondary equipment, elbow rest, retinal lens & lens case

8. Table

Including under table body that connect axis and table top and contains linear actuators to slide table out to access secondary examination equipment

9. Interface

Controls unit functions, further described in the next chapter 9.

10. Table suporting body

The body that contains the table raiser (actuator) and supports it

Figure 4 27: Annotated render of the new concept unit and its various parts

4.4 Conceptualisation: Table/chair unit

Design Phase

The ophthalmologist's own chair is not included in the concept. Fixing it and automating its height for optimal working posture as well was considered, but in the end chosen against. The ubiquitous routine of an ophthalmological patient visit: welcoming the patient; checking the patient's file at the desk; examining the eye at the slit lamp table; and going back to update the patient file and wrap up the visit; requires the doctor to roll around with their chair, from desk to slit lamp, etc. This means a fixed chair is not suited to the context.

Additionally, with the variety of chair preferences among Ophthalmologists, with nearly every doctor having another type of (preferred) chair, having all sit in the same type of chair, or in the best case, a limited set of chair types would not be acceptable.

For more information on the design process that resulted in this part of the concept, see Appendix 17.

4.4 Conceptualisation: Interface

Design Phase

4.4.4 Interface

The third part of this design concept is the interface, shown on the right. **The ophthalmologist interacts with this throughout the day to adjust the equipment and control the unit.** It controls the height of the table, height and depth of the chair, and mode (sitting or standing). The unit stores the set chair and table positions separately for both modes, so that the user can quickly cycle between them.

Buttons are grouped on the main panel by indentations that communicate their function group, and the size and position of the buttons conveys their function. Where possible, interactions are kept familiar, to facilitate adoption (Req. 5.2). In contrast to the current cluttered button grid with confusingly uniform buttons, the concept interface increases intuitiveness by placing the most used buttons closest to the user, and providing more differentiation between different keys. In an ophthalmological clinic room (figure 4.30, page 54), the patient and the slit lamp table are generally to the right of the ophthalmologist. Therefore, with the interface attached to the table unit, the left side of the interface is closest to the user. For this reason, the most used buttons are placed on the left.

A number of guidelines were used for the design of this control panel. Firstly, the interaction must be quick: it has to take the user the same or preferably less time to use as its current alternatives (Req. 5.4).

Secondly, the usage should be intuitive, thus require little to no prior instruction to understand and use (Req. 5.1.1). This means for instance that most used buttons are easiest to reach, more influential buttons are more prominent, and buttons that control complementary functions are grouped.

Figure 4 28: The Interface

4.4 Conceptualisation: Interface

Design Phase

The interface functions are shown in the figure below.

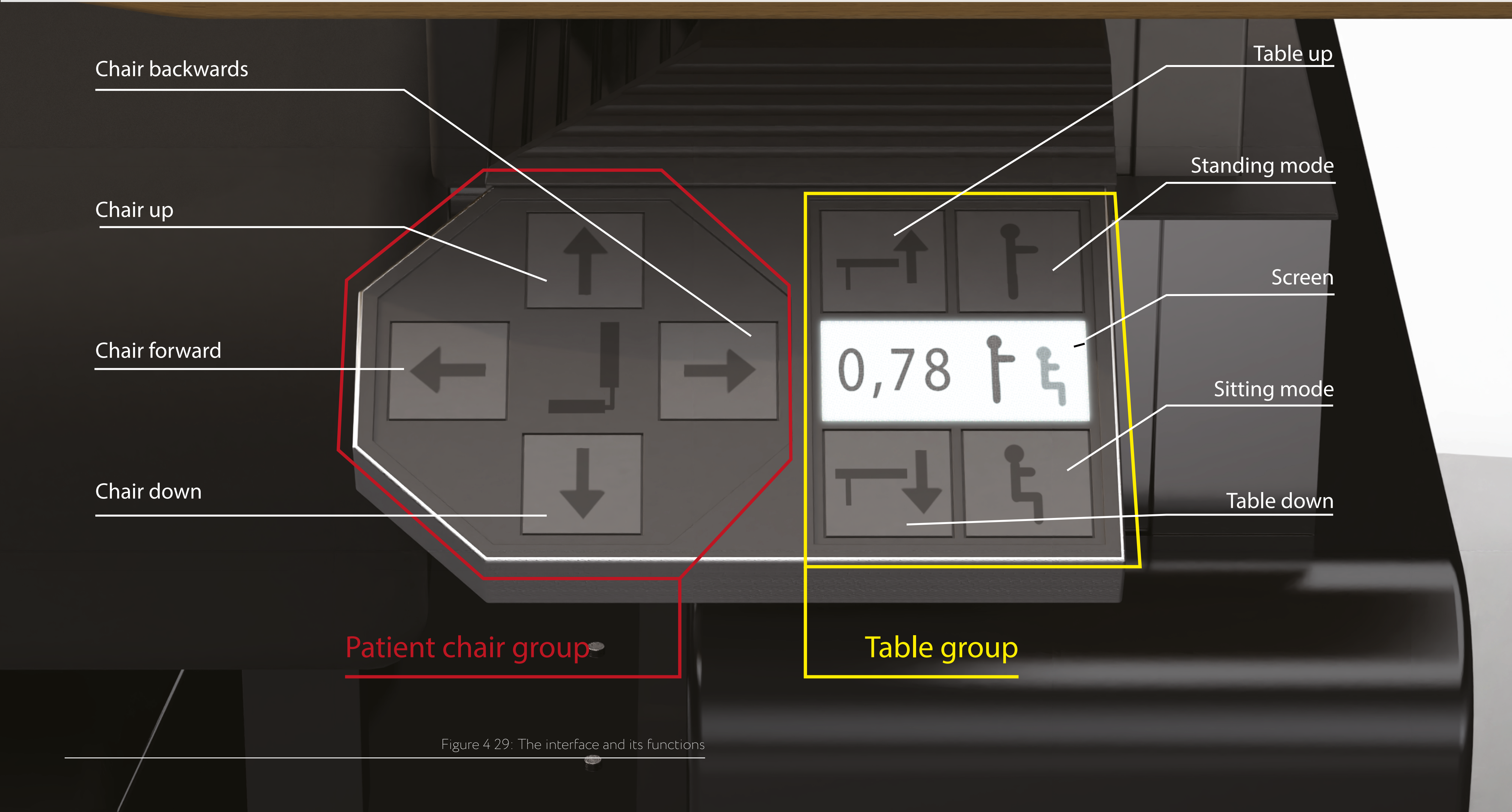


Figure 4 29: The interface and its functions

4.4 Conceptualisation: Interface

Design Phase

The interface functions are further elaborated on below:

- On the left of the main panel is the **patient chair group,** which controls the chair's height with the top and bottom keys, and depth with left and right keys. These are used for almost every patient. As this adjustment needs to be fast, considering average 10 minutes per patient, they raise or lower the chair a whole 3 centimetres per button press.

Figure 4 30: An ophthalmological clinic room with desktop (left), patient chair (middle) & slit lamp table (right)

Figure 4 31: The current control panel, cluttered and confusing

- On the middle right is the **screen**. This screen is not interacted with manually, but shows the height that the eyepiece is currently set to, relative to the ground. This is adjusted by the ophthalmologist, to their personal eye height at the beginning of the day. By thus linking the eyepiece height to a number, and making the number clearly present on the screen, height management can become consistent through time, making it unmistakable and easy to interpret. The screen also shows the current mode: sitting or standing, in the form of a solid, or opaque figure.
- Around the screen on the left are the table **height buttons**. These are interacted with, only at the beginning of the shift, to adjust the slit lamp table height in both modes. Every button click increases/decreases the height by 1 cm, keeping it held makes the number cycle up/down continuously, and after releasing the button for three seconds, the table moves into place. This interaction facilitates proper adjustment (Req. 1), in a timely manner (Req. 5.4).
- To the right of these are the **mode switch buttons**. The top one with standing icon engages standing mode, and the bottom one with sitting icon engages sitting mode. When the user switches to the other mode, the table and chair move to the height they were last set to in that mode.
- The **separate engage button** on the table (figure 4.32 below) swivels the slit lamp table in front of the patient, and is thus used for every patient visit. The concept table, similar to existing slit lamp tables, accommodates secondary examination equipment, such as eye pressure monitors, autorefractors or laser equipment. Shown on an existing table on the next page. These are accessed in the concept by holding down the engage button, making the table slide out linearly.

Figure 4 32: The separate engage button (The small octagonal button on the corner of the table)

4.4 Conceptualisation: Interface

Design Phase

The reasoning for the **split interface** is as follows. The positioning controls need to be available to the ophthalmologist at all times, as adjustments must be possible in any position or mode. This means that the interface has to move with the table when adjusting height and/or mode, as, if it were to stay in one place, it would become unavailable in standing mode or vice versa. There are two options for making the interface follow the table's movement: placing it on the table, or under the table. On the table was considered, but due to its movement, this would be impractical, as the interface would move with it. The panel therefore is found under the table, attached to a separate body on the column. It thus moves with the table in height, but not in rotation. This does introduce a new safety risk, as the user's hands are now in the way of the moving table. The way to solve this is to make all the adjustments with the main panel, and then move their hand away to the separate engage button, to (dis)engage the table, thus out of the way of the swivel table motion.

The interface is on a **hand panel** for several reasons. Firstly, the general preference for equipment interaction in the clinic among Ophthalmologists is for hand panels, as opposed to foot pedals. A hand panel is used currently, so keeping this the same will likely facilitate concept adoption. Secondly, the interaction with a hand panel evokes more precise adjustment, whereas a foot pedal is more likely to be used for general adjustments.

The interface's inclined face is chosen to make the panel more visible to the user, by directing it towards them. This is also likely to reduce glare. To further reduce glare, through light reflection, the panel has a matte finish.

Figure 4 33: Secondary examination equipment (encircled in yellow) on one of the current examination unit tables

4.4 Conceptualisation: Iterations

Design Phase

The chair/table unit went through many iterations throughout its development. Three of these iterations are shown below, with the final design on the right. The conclusions that underlined the respective versions are listed under them individually.

For more information on the design process that resulted in this part of the concept, see Appendix 17.

Iteration 1
- Table should have its own column to reduce main column load and simplify height adjustment
- The base plate needs to be less obstructive: thinner, and not to be a tripping hazard

Iteration 2
- Two columns need more support to be stable

Iteration 3
- Table needs to be shortened and its two movements, rotation and linear, split up into different parts
- Base plate should be split easing installation and transport
- It needs a phoropter pole

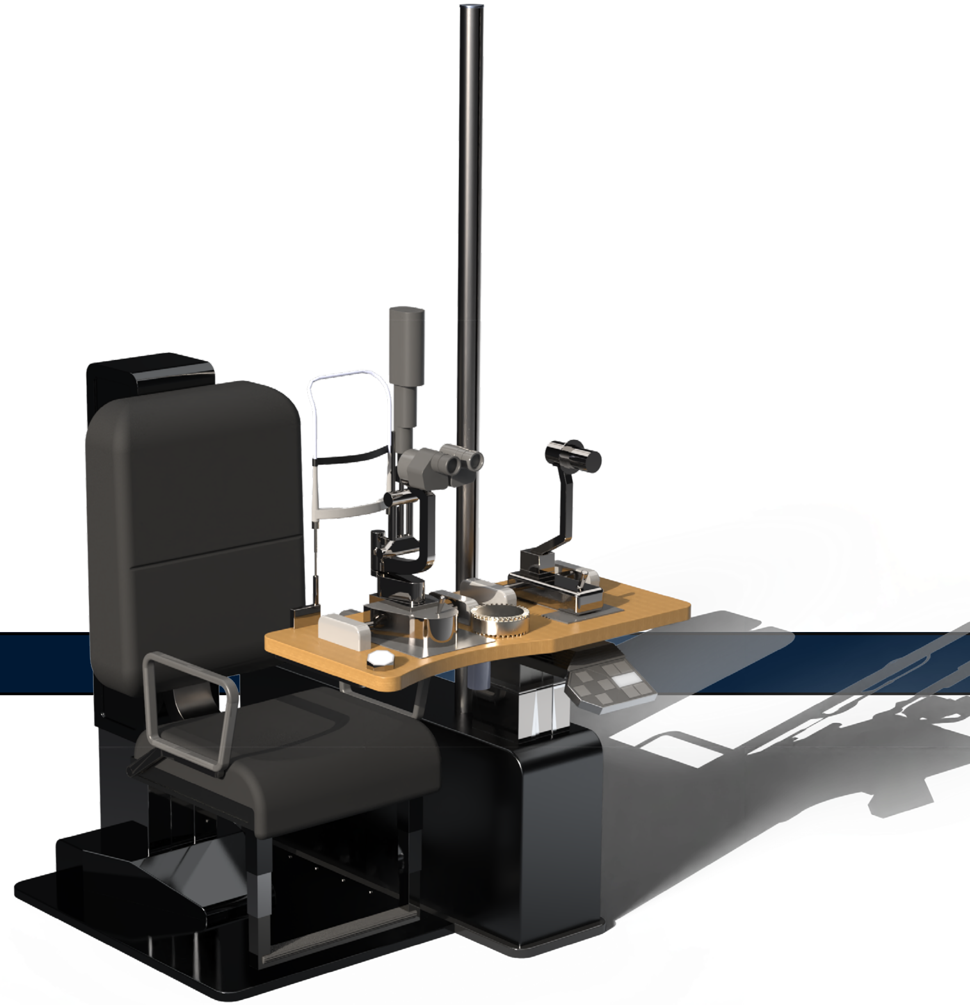


Figure 4 34: 3 Iterations of the chair table unit at subsequent stages of its development, and the final design on the right. Feasibility and ease -of-use increased greatly through these developments

4.5 User tests

Design Phase

During conceptualisation **I did three separate user tests**. Two of them with Ophthalmologists in their outpatient clinics and one with non-Ophthalmologists. The goal of the first two tests was to assess the validity of the measuring interaction, and the interface design, focussing on intuitiveness of the interaction, in the description given by IDF (2024): 'when a user is able to understand and use a design immediately—that is, without consciously thinking about how to do it—we describe the design as "intuitive" '. The third user test focused exclusively on the interface.

The ethics checklist as well as the informed consent form used during the tests are included in Appendices 3 and 4 respectively.

The main takeaways from these tests are shown below, with the final panel design on the right. The following pages will go into more detail. The user tests are described in full detail in Appendices 19, 20 and 23.

User test 1 - Takeaways
- More differentiation between buttons to communicate their functions
- Mode switch button should be on the front side of the panel

User test 2 - Takeaways
- Put most used buttons closest to user (left side)
- The unit needs to allow user to adjust chair depth (forward and backwards)

User test 3 - Takeaways
- Make height adjusters similar, to indicate similar functions.
- Button pairs should be more connected
- Make icons more communicative

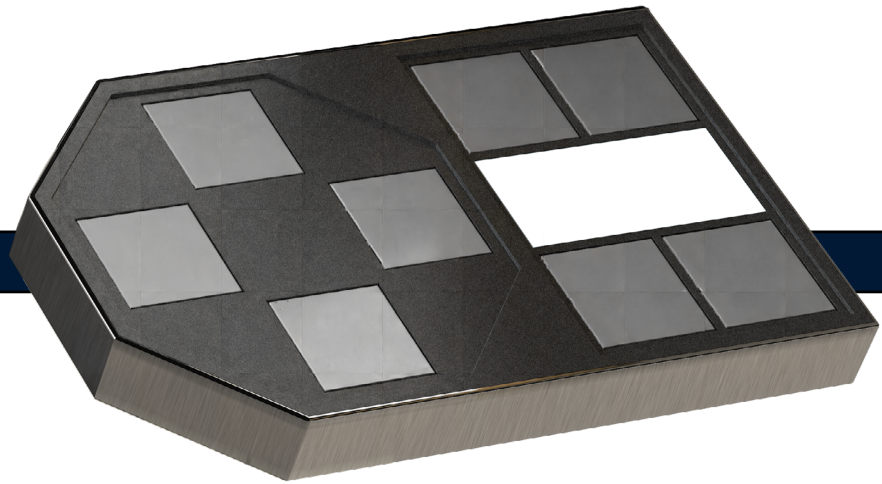


Figure 4 34: Interface prototypes for the 1st, 2nd & 3rd user tests, and the final interface design on the right. The ease-of-use was greatly increased through these tests

4.5 User test 1

Design Phase

The research question for the first test is: **Are the measuring interaction, and interface design intuitive enough, that they needs little to no explanation for the user to use it effectively?**

4.5.1 Method - Respondents

The respondents for the first and second test were recruited through NOG's channels. Respondent characteristics for the first test are included in the table below.

Table 4 2: Respondent characteristics – user test 1

Institution	Type of Institution (1. Hospital, 2. ZBC, 3. UMC)	Gender (m, v, x)	Years in profession (incl. other employers)	Respondent Nr. (User tests)
IJsselland Ziekenhuis	1. Hospital	V	19	1

4.5.2 Method – Activities & Environment

The test is conducted in the Ophthalmologists' usual working contexts in the outpatient clinic. The respondent was asked to read the research chapter in preparation for the test. On-site, they were given an explanation of a typical design project, and the project up until that point. The measuring stick and interface prototypes are then placed in their positions (Figure 4.33, right).

An interview with questions on the use of the concept is conducted. In this, the respondent is asked, without prior explanation what functions are embodied in the different buttons and screen. If the respondent answers correctly, the interface is deemed to be intuitive.

4.5.3 Conclusions

In this paragraph, conclusions are drawn to answers the research question.
Concerning the measuring stick:

1. The measuring interaction is fitting in the context. By doing this at the same time as the pupillary distance measurement for new Ophthalmologists, it fits seamlessly into the existing context.
2. The eye hole in the measuring slider needs to be further from the wall to be used effectively
3. The slider should be made to be collapsible, so that users do not walk into it when not using it

Concerning the interface:

4. The control panel being hand operated, as opposed to foot operated, is fitting
5. More differentiation needs to exist between the buttons on the interface to communicate their functions
6. The mode cycle button should be on the front of the panel, as opposed to the right side, as this side is out of the doctor's line of sight. Most Ophthalmologists' rooms are laid out with the doctor on the left and patient and slit lamp table on the right

Considering the above conclusions, the measuring interaction can indeed be called intuitive, albeit with a slight alteration of the physical product. The same could not be said for the interface. **The problems outlined in the conclusions above were attended in the next iteration, including more differentiation between the patient and table buttons, and a repositioned mode switch.** The new version was tested in the second user test.

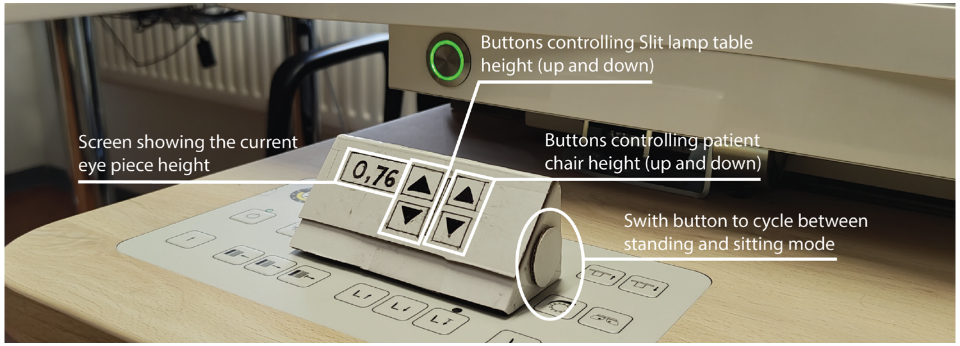


Figure 4 33: Interface prototype for the first user test. As shown, functions and the panel lay-out were still less developed

4.6 User test 2

Design Phase

The goal of the second test was to reassess the intuitiveness of the measuring stick and the redesigned interface. The research question for the second test is, again: **Are the measuring interaction, and interface design intuitive enough, that they needs little to no explanation for the user to use it effectively?**

4.6.1 Method - Respondents

The respondents for the first and second test were recruited through NOG's channels. Respondent characteristics for the second test are included in the table below.

Table 4 3: Respondent characteristics – user test 2

Institution	Type of Institution (1. Hospital, 2. ZBC, 3. UMC)	Gender (m, v, x)	Years in profession (incl. other employers)	Respondent Nr. (User tests)
Franciscus Gasthuis / Vlietland	1. Hospital	M	22	2

4.6.2 Method – Activities & Environment

The test is similarly conducted in the Ophthalmologists' own clinic, preceded by reading the research, and an on-site summary of a typical design project. An interview is then conducted. This interview has the same script as the first test. If the respondent correctly matches functions to buttons, the interface is deemed to be intuitive.

4.6.3 Conclusions

In this paragraph, conclusions are drawn from the research results, to answers the research question.

Concerning the measuring stick:

1. The measuring interaction is fitting in the context. By doing this at the same time as the pupillary distance measurement for new Ophthalmologists, it fits seamlessly into the existing context.

Concerning the interface:

2. The control panel being hand operated, as opposed to foot operated, is fitting
3. It is better to have the most used buttons close to you, meaning on the left of the interface. As units are generally on the right of the doctor, buttons on the left of the panel are closest to the user. Thus placing the most common panel interactions on the left increases ease-of-use.
4. The unit needs to allow the ophthalmologist to adjust the chair's depth (forward and backwards) to allow more corpulent patients to be examined equally

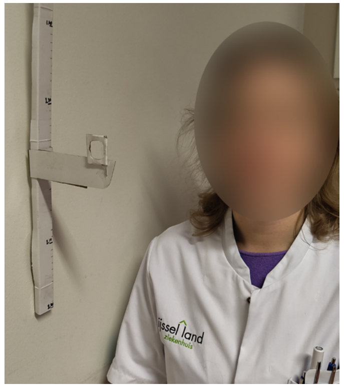


Figure 4 34: Ophthalmologist using prototype of the measuring stick

Considering the above conclusions, the measuring interaction can indeed be called intuitive, or needing little to no explanation for the user to use it effectively. The same could not yet be said for the interface. **The problems outlined in the conclusions above were attended in the next iteration, including repositioning of buttons to place common interactions closest to the user, and the inclusion of chair depth control.** The new version was tested in the third user test.

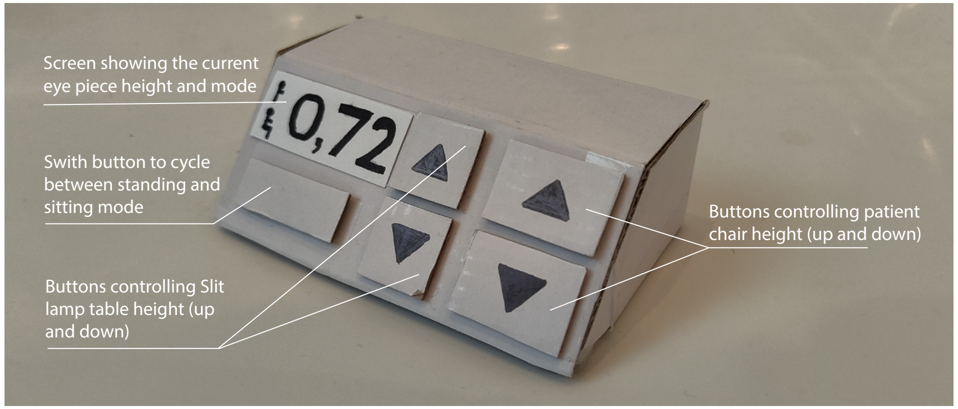


Figure 4 35: Interface prototype for the second user test. As shown, the lay-out is updated compared to the last prototype

4.7 User test 3

Design Phase

The goal of the third test was to reassess the intuitiveness of the interface design. The research question for the third test is: **Is the interface design intuitive enough, that it needs little to no explanation for the user to use it effectively?**

4.7.1 Method - Respondents

This third test is conducted with 3 respondents, whom are not Ophthalmologists. This was deemed fitting as what is tested, intuitiveness, does not require ophthalmological background knowledge but rather common logic. This also reduces the time necessary to set up the on-site tests, thus making a higher respondent count possible. Respondent characteristics for the third test are included in the table below.

Table 4 4: Respondents characteristics – user test 3

Respondent Nr. (User tests)	Gender (m, v, x)	Age
3	V	25
4	M	23
5	V	22

4.7.2 Method – Activities & Environment

The test is preceded by an explanation of the problem of musculoskeletal injuries in Ophthalmologists, the equipment used in the current context, and a summary of the redesigned chair/table unit.

An interview with questions on the use of the concept is then conducted in which the respondent is asked, without prior explanation what functions are embodied in the different buttons and screen. If the respondents answer correctly, the interface is deemed to be intuitive. The prototype used for this has blank buttons, to first assess the interface in terms of button placement and sizing (Figure 4.36, top right). After assessing this, the interface is shown with its button icons (Figure 4.37, bottom right), and the respondents are asked if these change their answers.

4.7.5 Conclusions

Concluding from this test, the current panel does not provide enough guidance with its form and layout, to instantly tell the user its functions.

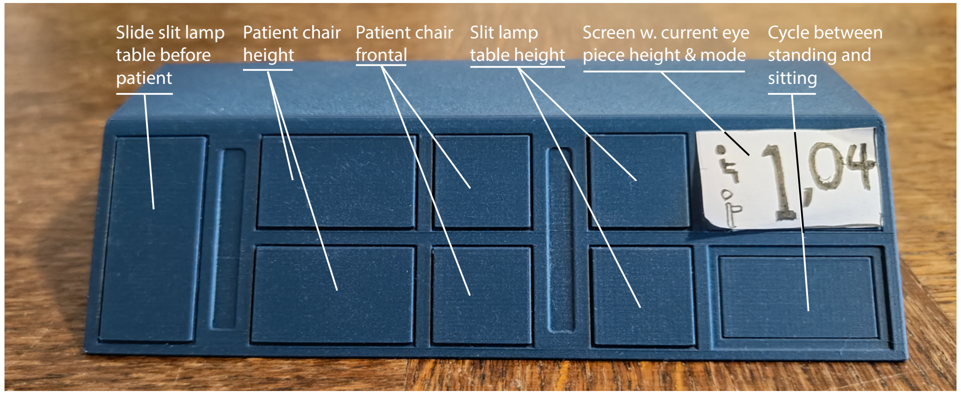


Figure 4 36: Prototype with blank buttons to not influence the respondents' answers. As shown, the functions were expanded and lay-out improved.

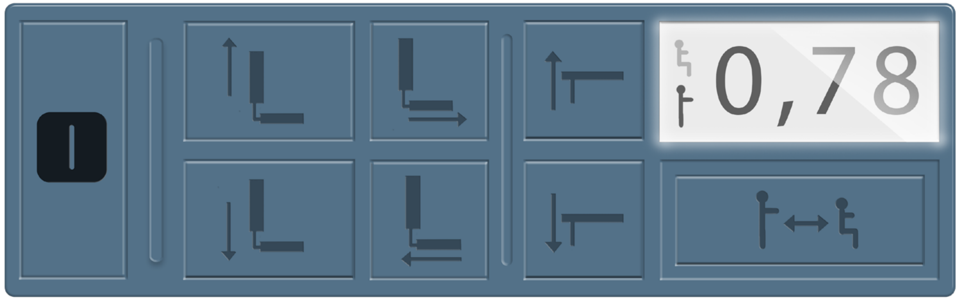


Figure 4 37: Prototype with button icons, shown later in the test

Several clear design guidelines can be distilled:

1. Make the chair-height buttons and table-height buttons the same size, shape and positioning to indicate their similar functions.
2. Secondly, up/down and back/forth button pairs should be more connected, either visually or physically.

4.7 User test 3

Design Phase

3. Thirdly, by making the chair and ophthalmologist icons face each other, as opposed to in the same direction, you communicate to the user that these are distinct opposites.
4. Lastly, indentations in the panel are effective at communicating the separation of elements, but more clarity should be provided communicating what they separate.

Using these guidelines, I designed the final interface that is presented in this report.

This user test and the previous two are described in full detail in Appendices 19, 20 and 23.

4.8 Advantages & Challenges

Design Phase

At the start of sub-chapter 4.4: Conceptualisation, I stated the main advantages of the concept, when compared to the current alternative. In this sub-chapter, having described the concept in detail, I will further elaborate on these advantages.

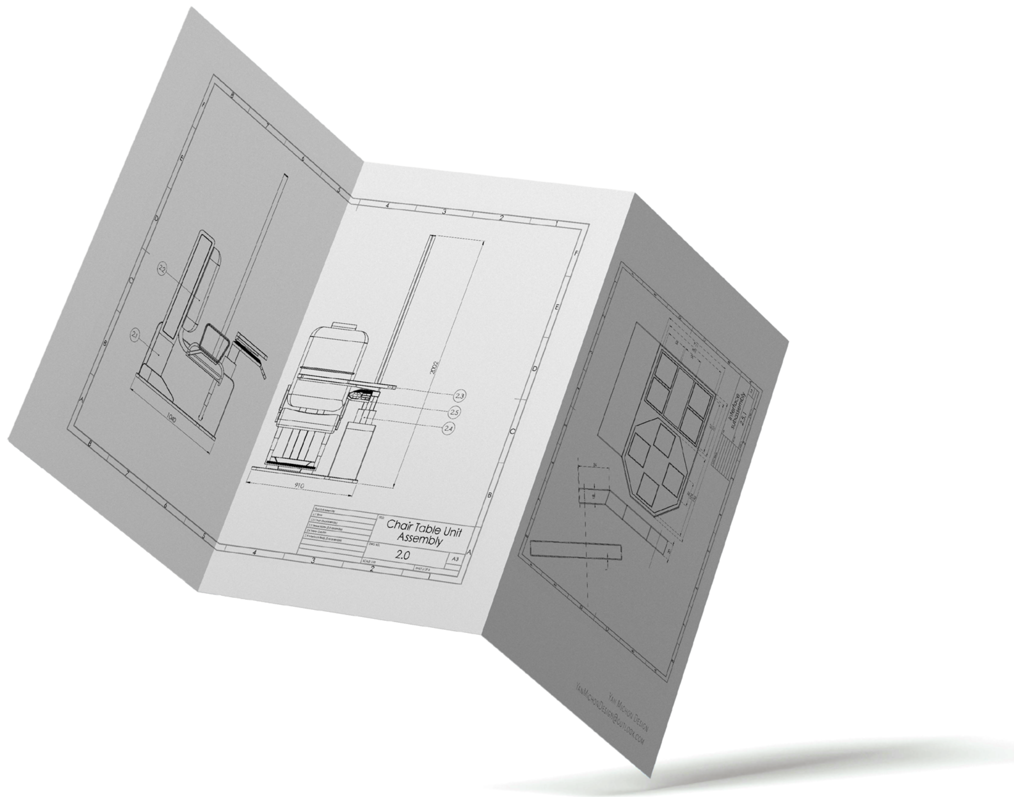
The main advantage to this design, and raison d'être of this concept and project to begin with, is **improved ergonomic posture for the ophthalmologist** (Req. 1). This is achieved through several factors.

Firstly: **extended adjustability.** The component layout of current examination units, does not facilitate the necessary height range for all Ophthalmologists to work ergonomically. The concept realises this, allowing Ophthalmologists of any stature to work ergonomically, sitting or standing up, without sacrificing patient comfort (Req. 2). Adjustability, furthermore, is not only literally extended in range, but also **extended in precision.** The concept allows adjustments to the table position to be made in 1cm increments, instead of the button-held continuous movement used currently, which is prone to overshooting and readjusting. This gained precision reinforces the Ophthalmologists' behavioural change of fine-tuning and prioritising their own posture, ensuring long-term health and well-being.

The second advantages to this design, is **quicker adjustment**. The concept's table, which effects the posture of the ophthalmologist, can be set to the perfect height quicker and with more precision, without overshooting or readjusting due to the preceding eye height measurement.

The third advantage is the **ease of use** (Req 5.1). The straightforward once-off eye measurement can be included in the existing PD measurement (Req. 5.2.1). The interface secondly, carries clearer, more insightful controls. The eyepiece height being clearly displayed furthermore makes the ideal ergonomic setting unmistakable and easy to interpret, allowing height management and ergonomic posture to become consistent through time, with minimal effort from the ophthalmologist (Req. 10).

Lastly, the concept fits in the ophthalmologist's room with no adjustments (Req. 3), and the interaction **fits seamlessly into the existing context** (Req. 3 & 5.2). Many of the Ophthalmologists I interviewed in my research, mentioned feeling like there is no time to adjust the equipment to be able to work ergonomically. Height Matcher solves this, both reducing the time commitment, and ensuring ergonomic posture for ophthalmologist and patient at the same time.



Recommendations.

In this chapter, I will list my recommendations, as to how this concept should be developed further, into a producible product. Secondly I will provide advice on ergonomic improvements that can be made in the sector using the means currently available. Lastly I will outline where I think further research could be valuable, in uncovering more opportunities for improvement.

Chapter 5.

3. pages

5.1 To be determined

Recommendations

Firstly in this sub-chapter, I will outline several **aspects of the concept that should be developed further, for the concept to be developed into a producible product.**

5.1.1 Material Strength

The proportions of the final concept are primarily based on existing alternatives where possible. This applies for instance to the size of the baseplate, the measurements of the table, the chair construction, the thickness of the table column, phoropter pole, and table supporting body. Where this wasn't possible such as with the posterior chair column or the motorisation of the rotating table, as these do not exist in current alternatives, I consulted industry representatives (NOG Conference & Industry rep. Interview). In subsequent development, further research and testing should be conducted to specify the exact measurements for the concept's components, including material specification and strength analysis.

5.1.2 Components and actuators

Secondly, the proposed posterior extending column combines a large movement range, with centimetre precision. In future iterations, research should be conducted to determine one of two solutions. Either a single actuator can be used to realise this motion. Whether an actuator like this is cost-effective is part of this consideration. The second scenario is the implementation of a two-step movement. In this way, one actuator with low accuracy, but large range, would be used to raise the unit from sitting to standing mode, spanning the largest part of the height adjustment. A secondary actuator with a shorter range, but higher accuracy, would bring the unit to the exact height, set by the user. with these actuators working in tandem, a quick and accurate interaction can still be realised.

5.1.3 Necessity of a measuring stick

With the measuring stick furthermore, I have aimed to propose a design that makes the measuring interaction as simple, quick, and accurate as possible. I however also concede the point that this specific measurement, could potentially be taken with a simpler tape-measure as well. While this alternative would not be as precise as my proposal, it would reduce initial cost and save on installation time. I posit that the increase in accuracy of the measurement, gained by using my design justifies these points, but further research and development should be done to determine whether the accuracy with which you can measure eye height, using a tape-measure, is consistent enough in the context, when compared to the designed proposal.

5.1.4 Button panel or touchscreen

The concept interface is a physical button panel, as opposed to a touchscreen. This was chosen for several reasons. Firstly, a physical panel is less likely to be tapped by accident: a touchscreen can easily be pressed unintentionally, and with the patient chair's controls, this cannot be allowed to happen. Secondly a button panel is more robust: it is much less likely to malfunction and doesn't break as easily. Thirdly, a touchscreen always uses energy, even when idle, while a button panel is more conservative in its energy usage. Combined with the higher footprint in terms of material costs of rare earth materials in touchscreens, and their higher intricacy complicating recycling, the physical panel is more environmentally friendly. Even with these arguments, the advantages of touchscreens over button panels, such as greater design flexibility and higher potential degree of intuitiveness cannot be denied. Future research could determine whether these possible advantages weigh up to the disadvantages.

5.2 Advice

Recommendations

I argue that the proposed concept and interaction scenario is the optimal examination context for an ophthalmologist in terms of ergonomics and ease-of-use. There are however also several improvements that can be made in the sector right now, using the means currently available, that could significantly improve Ophthalmologists' long term health. In this sub-chapter, I present **a list of actionable advice, based on my research, that could help improve the ergonomic working conditions of Ophthalmologists, before the implementation of my design.**

5.2.1 Adjust the equipment to yourself

My research points out that many Ophthalmologists adjust their examination unit to the patient, instead of in favour of their own healthy posture. It is important for Ophthalmologists and other healthcare workers, regardless of equipment characteristics to priorities their own long-term health, over the patient's short-term comfort. By prioritising employee health, the doctors can improve and protect their health and employers gain higher employee satisfaction and retention. My specific advice to medical professionals, including Ophthalmologists, using a slit lamp (table) is to adjust the equipment once, properly, in the morning and keep it constant throughout the day, only changing the patient chair.

5.2.2 Work in fixed rooms

My research points out that the frequent switching of rooms decreases Ophthalmologists' motivation to ergonomically adjust the examination equipment every time they arrive in a new room. By working in fixed rooms as much as possible, Ophthalmologists are more likely to adjust the equipment for ergonomic posture as, with less rotating between rooms, they do not have to readjust quite as often. Another option is to implement more time per room-switch to give the doctor time to make the necessary adjustments.

5.2.3 Patient and doctor in line

My research points out that by placing the examination unit such that the patient is perpendicular to the ophthalmologist, the latter twists more to face the patient during conversations. This persistent spinal torsion is connected to the development of musculoskeletal injuries and should be avoided as much as possible. By placing the examination unit such that the patient is in line with the doctor as much as possible, spinal flexion is minimised. It appears that one reason units are currently placed perpendicular to, instead of parallel to the ophthalmologist, is that units with fixed proportions are installed into pre-existing spaces, where sometimes the relative measurements of device and space do not allow for more optimal positioning. This, therefore, is also something to keep in mind in the construction of new outpatient clinics and selection of equipment tables.

5.2.4 Guidelines & Advice

During this project I met multiple Ophthalmologists that said they think they work in a way that is suboptimal for their own long-term health. Among others, they often mention that this is because they are unsure how to work in a proper ergonomic way. In none of the medical institutions I visited during my research, have I found any guidelines or advice that help the doctor develop and maintain a good posture. I have been similarly unaware of emphasis on this part of the profession in the education, which is in contrast to other medical specialisations where ergonomics in the workplace is an important part of the curriculum. By implementing the adoption of good posture as a part of the education leading into the profession of ophthalmology and providing clearer advice on proper posture within medical institutions, Ophthalmologists would be more likely to work in a healthy manner.

5.3 Future research

Recommendations

The above sub-chapter outlines the advice that I can currently give to the sector with the research I have done. There are also several areas that, while I was unable in the time available to form clear advice on, I believe are influential in the context and can be fruitful **to conduct further research into.**

5.3.1 Slit lamp design

Early on in this thesis project I realised the degree of conservatism that exists around slit lamps, in terms of their design and functions. A decision was made to focus on the ophthalmic equipment around the slit lamp within this thesis, and leave the latter untouched. I believe it can be a valuable design exercise to further analyse the slit lamp and improve upon its current construction. Industry representatives I have spoken to claim a similar point, saying that if a designer were to redesign the slit lamp with today's possibilities, it would not look like it does today (Appendix 21: NOG conference).

5.3.2 Clinic layout Optimisation

My current advice is to have ophthalmologist and patient in line with one another to improve the ophthalmologist's spinal posture by reducing twisting. What has not yet been included in this advice is position of patient companions in the space. While half of the table units in the clinics I visited were sub-optimally positioned, perpendicularly, and half in the better parallel position relative to the ophthalmologist, in all 15 of them, the companions are behind the doctor. This introduces another problem, even in the clinics with the better parallel positioning as, while the ophthalmologist does not need to twist much to talk to their patient, they still need to turn around to address the companions. Further research into how to optimise space usage in ophthalmic clinics could therefore be valuable. Factors to consider include:

- Optimal positioning of existing equipment relative to the ophthalmologist, patient and companions.
- Influence of floor space (big or small room, long room, square, etc.) on the layout of ophthalmic equipment and other furniture in the space and its influence on the ophthalmologist's posture.
- In result of this: the optimal floor plan proportions of an ophthalmic clinic, in regards to the construction of new clinics.

5.3.3 Advice & Education

My current advice is implementing the adoption of good posture as a part of the education leading into the profession of ophthalmology and providing clearer advice on proper posture within medical institutions, to make Ophthalmologists more likely to work in a healthy manner. Research should be done on how best to implement these better ways of working into the education. A best case scenario would be to connect education and medical institutional guidance to reinforce a better, healthier way of working.

5.3.4 Division of work

During my research, a supposed correlation was found where, when more supporting staff (TOAs, Optometrists, residents) is present, Ophthalmologists report fewer work related musculoskeletal injuries. On the other hand, the higher degree of responsibility, and more managerial duties seems to add more mental pressure to the ophthalmologist's work. A connection thus seems to exist between division of work and musculoskeletal injuries as well as cognitive load experienced by Ophthalmologists.
With the time and means available in this thesis, this correlation could not be unequivocally confirmed, so further inquiry could be valuable to confirm the existence and/or nature of this correlation, and define better ways of dividing work to minimise complaints. Special care should be taken in researching whether in this redivision of work, reduction of musculoskeletal injuries in Ophthalmologists does not cause an increase in these complaints in the supporting staff.

I believe that the implementation of the recommendations outlined in this chapter can help improve the long-term health of Ophthalmologists, and thus improve the quality of care and swiftness with which patients can be received and treated in Dutch medical institutions.

Acknowledgements.

I would like to thank my team, as well as all the experts and medical specialists who gave me their time during this thesis. My company contact Daphne Albers and her colleagues at NOG, graduation chair Pieter Jan Stappers, academic mentor Gonny Hoekstra, the various Ophthalmological clinics that I was fortunate enough to visit and their Ophthalmologists who allowed me to observe their work, the helpful team at MID, the industry representatives that gave me their time during this project and the many others that helped me in the past months.

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Chapter 7.

3. pages

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I look forward to meeting you

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Appendices.

The Appendices were put in chronological order, as much as possible, as to their content's occurrence during the project. As such, the original assignment is included first, followed by my graduation proposal, continuing through information from the research phase, into design process descriptions, user tests, and finally a Glossary.

Description of Appendices

Appendices

This section contains 25 separate Appendices.

Appendices 1 through 4 include project documents such as the initial assignment, my graduation proposal, and documents on project ethics.

Appendices 5 through 12 span the process from Pre-research, Context analysis, and Research Script, to Results and the resulting List of requirements.

Appendices 13 through 24 span the process from Design directions, Conceptualisation, and User testing, to Expert interviews, and finally the Technical drawings for my concept.

The Appendices are ended with a Glossary.

Appendices - Table of Contents