Verein zur Förderung der Rehabilitationsforschung in
Hamburg, Mecklenburg-Vorpommern und
Schleswig-Holstein

STAGE: ein anthropometrisch unterstützendes Framework für die physikalische Interaktion mit digitalen Artefakten durch Menschen mit körperlichen Behinderungen – Machbarkeits- und Akzeptanzstudie

Andreas Schrader

Abschlussbericht

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Projektleiter: Prof. Dr.-Ing. Andreas Schrader
Projektmitarbeiter : Dr.-Ing. Bashar Altakrouri &
Daniel Burmeister (M.Sc.) & Dennis Boldt (M.Sc.)

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Korrespondenzadresse:
Prof. Dr. Andreas Schrader
Ambient Computing AG am Institut für Telematik
Universität zu Lübeck
Ratzeburger Allee 160
23562 Lübeck
Tel. (0451) 500 3724
schrader@itm.uni-luebeck.de

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Kurzfassung

Natural User Interfaces (NUI), also Nutzerschnittstellen mit möglichst natürlicher Interaktion, kommen bereits in vielen Gebrauchsgegenständen und Haushaltsgeräten zum Einsatz. Diese bieten dabei nicht nur die Möglichkeit neuer Interaktionsfunktionalitäten, sondern gleichzeitig auch neuartige und eindrucksvolle Erfahrungen für Nutzer. Jedoch erfordern gerade diese Interaktionsparadigmen ausreichend hohe kognitive und physische Fähigkeiten. Insbesondere Benutzergruppen mit Beeinträchtigungen, wie einer eingeschränkten Mobilität und Stabilität von Gelenken oder einer begrenzten Kontrolle der Willkürmotorik, können diese Nutzungsschnittstellen eine Überforderung hinsichtlich der jeweiligen physischen Fähigkeiten erzeugen. Gleichermaßen kann dies in Anlehnung zur Digitalen Kluft (Digital Gap) zu einer Art Physischen Kluft (Physical Gap) führen und dadurch neue Herausforderungen in der Interaktion bedingen. Im Rahmen dieses Projekts wurde eine dreiteilige Studie, bestehend aus einer Guessability-Studie mit 20 gesunden Teilnehmern, einer Guessability-Studie mit 13 beeinträchtigten Teilnehmern und einer Wizard-of-Oz Machbarkeitstudie mit 21 Teilnehmern, durchgeführt. Diese Studie zielte auf die Beobachtung von nutzerspezifischen Adaptionsstrategien (Körpereinsatz, nutzerdefinierten Gesten, etc.) zur Bewältigung von gestenbasierten Interaktionsaufgaben unter physischen Einschränkungen. Besonderes Augenmerk galt der Untersuchung des Einsatzpotenzials von Ganzkörper-Motion-Gesten für gesündere und leichter zugängliche Arbeitsplätze sowie einer Evaluation der Machbarkeit des propagierten Konzepts der sogenannten "Interaction Ensembles" (Verbünde von Interaktionsgeräten) als einen möglichen Ansatz zur Kompensation von physischer Beeinträchtigung bei Interaktionsaufgaben.

Unsere Studie zeigt auf, dass unter beiden Testgruppen (gesund und beeinträchtigt) eine starke Tendenz in Richtung individueller Motion-Gesten anstatt vordefinierter und einheitlicher Gesten-Sets vorherrscht. Vielmehr nutzten die Teilnehmer unterschiedliche Körperteile zur Ausführung von Gesten, wobei kein allgemein bevorzugter Körperteil gefunden werden konnte. Gleichzeitig zeigten die Ergebnisse jedoch, dass eingeschränkte Teilnehmer der Studie weitaus unterschiedlichere und individuellere Gesten-Sets erzeugten als gesunde Teilnehmer. Darauf begründet ist dies ein starkes Indiz, dass physische Einschränkungen neue Anforderungen hinsichtlich Personalisierung und nutzerdefinierten Gesten darstellen. Weiterhin konnten hohe Übereinstimmungswerte unter den Teilnehmern für Gesten von binären Aufgaben (an/aus, erhöhen/vermindern, etc.) mit geringer Komplexität und ohne die Voraussetzung von spezifischem Wissen über die Funktionsweise eines Systems beobachtet werden. Die Ergebnisse von durchgeführten Interviews zeigen die Dringlichkeit der individuellen Anpassbarkeit von Gesten. Viele Nutzer wiesen hierbei explizit auf ihre Präferenz von selbsterstellten Gesten gegenüber vordefinierter Gesten-Sets hin. Ähnlich zur selbstständigen Definition von Gesten, bevorzugt ein Großteil der Teilnehmer ebenfalls selbstdefinierte Ensembles. Insgesamt weist dies darauf hin, dass Benutzer die Steuerung von interaktiven Systemen an persönliche Bedürfnisse und Präferenzen anpassen möchten.

Wir konnten weiterhin feststellen, dass ein Großteil der Teilnehmer unterschiedliche Strategien verwendete, um Motion-Gesten zu definieren. Obwohl viele Unterschiede zwischen den gesunden und den beeinträchtigten Teilnehmern beobachtet werden konnten, nutzten die meisten Probanden metaphorische, reale Gesten, ein einfaches, direktes Mapping, sowie Alltagsbewegungen und Konsistenz, um Gesten zu definieren. Während die gesunden Teilnehmer bereits bekannte Gesten aus vorherigen Erfahrungen mit gestenbasierten Geräten direkt auf die Studie übertrugen, haben die beeinträchtigten Studienteilnehmer ihre Gesten größtenteils spontan definiert. Für die Definition von Ensembles wurden ebenfalls verschiedenste Strategien angewandt. Einfachheit, Innovation, bisherige Erfahrungen und eine begrenzte Anzahl involvierter Interaktionsgeräte (2 — 3) wurden hierbei als wichtige Faktoren erachtet.

Grundsätzlich waren alle Teilnehmer in der Lage, die ihnen gestellten Aufgaben während der Guessability-Studien zu erledigen. Dies zeigt, dass Ganzkörper-Gesten zugänglich und vor allem für alle Nutzer möglich sind. Gleichzeitig haben diese das Potenzial bestehende physische Barrieren zu reduzieren. Der Großteil der Teilnehmer hatte dabei keine Schwierigkeiten, sich Gesten zu überlegen oder diese auszuführen. Wie erwartet, wurden Gesten von gesunden Probanden ohne Einschränkungen als geringfügig einfacher empfunden. Die Probanden waren auch der Meinung, dass die von ihnen erdachten Gesten gut zu den jeweiligen Aufgaben passen. Unsere Ergebnisse zeigen, dass die kognitive Beanspruchung beim Erdenken von Gesten von den Probanden als gering erachtet wurde, auch wenn physische Einschränkungen simuliert wurden. Die Studienergebnisse zeigen gleichermaßen, dass ein Großteil der beeinträchtigen Probanden bereit sind, ihren gesamten Körper für Motion-Gesten zu verwenden. Demgegenüber steht die Mehrzahl der gesunden Teilnehmer, die diesen Einsatz großteilig ablehnten.

Ein Großteil der gesunden Teilnehmer und die überwiegende Mehrheit der beeinträchtigten Teilnehmer sehen Potenzial im Einsatz von Ganzkörper-Gesten für ein gesünderen Arbeitsstil im Büro. Dies deutet auf eine generelle Akzeptanz des Einsatzes des gesamten Körper zur Interaktion im Büroumfeld hin. Die Ergebnisse unterstützen ebenfalls unsere Hypothese, dass Ensembles im Büroumfeld eine Vielzahl von potenziellen Vorteilen mit sich bringen, wie etwa eine gesteigerte Effizienz oder eine optimierte Ergonomie durch den Einsatz von personalisierten ambienten interaktiven Systemen unter der Berücksichtigung von anthropometrischen Nutzerfähigkeiten und -einschränkungen. Somit könnte ein bestehender Arbeitsablauf im Büro gleichzeitig Teil eines Gesundheits- und Rehabilitationstrainings werden. Auf lange Sicht könnten Ensembles, unterstützt von adäquaten Feedback-Technologien und -Techniken, ungesunden physischen Verhaltensweisen und der Monotonie sich wiederholender Prozesse vorbeugen. Ein Großteil der Teilnehmer war der Meinung, dass der Einsatz des gesamten Körpers für Motion-Gesten einen positiven Einfluss auf die Produktivität und die Konzentration innerhalb von Büroumgebungen haben könnte.

Die praktischen Erfahrungen des Konzepts der Interaction Ensembles wurde von den Probanden grundsätzlich als positiv erlebt. Der Großteil der Teilnehmer empfand das selbstständige Definieren und Ausführen dieser Ensembles als leicht. Ensembles mit geringerer physischer Besanspruchung wurde hierbei gleichzeitig auch als einfacher in der Ausführung empfunden. Beispielsweise wurden für die Teilnehmer unbekannte kollaborative Ensembles als einfacher in der Verwendung empfunden, als individuell angewandte Ensembles. Dies könnte durch die Tatsache bedingt sein, dass die Teilnehmer hierbei nur die Hälfte der vollständigen Bewegung ausführen mussten. Einige Teilnehmer äußerten, dass die hinter den Ensembles stehende Technologie perfekt funktionieren müsste, um eine Akzeptanz hervorzurufen. Gleichzeitig lehnten einige Teilnehmer dieses Konzept aus verschiedensten Gründen ab, wie z.B. aufgrund der anfallenden kognitiven Belastung beim Erinnern von komplexen Konfigurationen. Dennoch würde ein Großteil der Probanden den Einsatz von Interaction Ensembles ohne weitere Einschränkung für alltägliche Büroaufgaben akzeptieren. Weiterhin war sich ein Großteil der Teilnehmer einig, dass Ganzköper-Motion-Gesten und Interaction Ensembles einem gesünderen Arbeiten zuträglich wären. Zusätzlich könnte sich die überweigende Mehrheit der Teilnehmer vorstellen, das Büro als Trainingsumgebung zu verwenden, insbesondere zur Durchführung von Rehabilitations-Übungen. Weiterhin war sich ein Großteil der Teilnehmer einig, dass Ensembles ihre Konzentration und Produktivität nicht oder wenn, dann positiv beeinflussen würde.

Die Mehrheit der Probanden der Studie sprach sich für individuelle Ensembles aus. Die von den Teilnehmern der Studie selbsdefinierten Ensembles wurden weitestgehend personalisiert. Dadurch begründet konnten keine einheitliche Ensemble-Konfiguration ermittelt werden. Dies deutet erneut auf eine generelle Tendenz zur Individualisierung von Interaktionsmöglichkeiten hin. Die Mehrheit der Probanden bewertete die kognitive Beanspruchung zum Erlernen und Erinnern von selbstdefinierten Ensembles als gering. Gleichzeitig waren sich die Probanden einig, dass eine adäquate Handlungsunterstützung von Nöten ist, um neue Ensembles zu erlernen.

Wir sehen diese Studie als Ausgangspunkt zur Identifikation der Machbarkeit und der Akzeptanz des Einsatzes von Ganzkörper-Motion-Gesten und Ensembles für einen gesünderen Arbeitsstil. Die in diesem Bericht diskutierten Ergebnisse zeigen das große Potenzial und die hohe Akzeptanz des Interaction Ensembles-Ansatzes auf.

Executive Summary

Natural User Interfaces (NUI) such as touch-based and motion based gestures are currently found in wide range of commercial devices and products. Such technologies are increasingly adopted in various daily-living scenarios and application domains which allow for more innovation and engagement with the physical surroundings. Nonetheless, the use of NUI often requires high demand of physical and cognitive capabilities. This demand may challenge various user groups with impairments. In this project, we study a

concept for dynamic creation and configuration of Interaction Ensembles that are mainly adapted to the user's physical needs and abilities. The main goal of this project is to evaluate the possibilities to apply and use Interaction Ensembles in real world scenarios and to examine the acceptance of using this concept in the office environment. The project primarily focuses on people with physical impairments (especially arm and hand related impairments) undergoing rehabilitation.

This document provides an overview of the design and performance of a three-fold study to examine the concept of Ensembles. Firstly, it presents a brief summary of related work in this area. Secondly, the experiment design is discussed. Thirdly, the study's main results are analysed and discussed. Finally, the main conclusions and lessons are presented.

CONTENTS

Chapter A

INTRODUCTION

Natural User Interfaces (NUI) highly utilize the users' cognitive and physical abilities. For instance, touch-based devices require good coordination and control of arm, hand and finger movements (sometimes good sense of touch and grip). Extensive use of NUI may challenge various user groups suffering from impairments, especially limited mobility and stability of joints or limited control of voluntary movements. Such impairments have a direct negative influence on the ability to execute particular movements required for the interaction and may also lead to a complete inability to interact. This often leads to a number of consequences ranging from applying personal adaptation strategies to overcome the impairment (e.g. using the nose touch instead of a figure touch) to the exclusion of the use of important devices and related applications in daily life (Digital Divide). Interaction Ensembles offer various benefits in different areas of daily living (herein we focus on the office environment) such as a better working efficiency and optimized working conditions. Interaction Ensembles imply the full potential of NUI technologies. Instead of concentrating of the physical limitation and setting up special accessible workplaces, personalized Interaction Ensembles adapt to the interaction resources and possibilities by carefully considering the users' anthropometric profiles. This enables typical office tasks to become rehabilitation exercises and blur the boundaries between work and physical exercise. Hence, in many cases the need for the establishment of so-called dedicated disabled equitable jobs could be eliminated. In the long run, appropriate persuasive feedback techniques may aid to avoid bad working habits, to prevent repetitive processes through adaptive workflows, to seamlessly integrate rehabilitation exercises into work processes, and to utilize the sensory capabilities of NUI technologies for automatic detection of health, diagnostics and telemedicine support [?]. In this project, we examine two main hypothesis: (1) the diversity of users' anthropometric abilities leads to inability to achieve a single canonical gesture set for all users; and (2) the Interaction Ensembles approach is an accepted approach for improved and optimized working conditions for physically impaired users. These hypothesis will be investigated by an exploratory elicitation study in the context of office work for users with physical hand and/or arm impairments, with the focus on the following scientific issues:

1. Accepted resp. non accepted interaction modalities of physical interaction (e.g., arm movements in public).
2. Adaptation-strategies for handling NUI-techniques corresponding to physical impairments.
3. Selection and composition strategies for Ensembles within a certain usage context.
4. Comparison of the results (1) — (3).

A.1. Related Work

Currently NUI-concepts emphasis the development of Human-Machine-Interfaces. NUI enables interaction on application of natural body movements and gestures [40]. Touch-sensitive screens on mobile devices (Smartphone, Tablet, etc.) are the visible manifestation in products.

Current research focusses on developing novel NUI-components to the conceptualization of intelligent environments (SmartHome, SmartOffice, SmartBuildings, etc.). Especially gesture-based techniques are an often postulated instrument for realizing unobtrusive interaction („embodied interaction") [35]. Thus for instance Smart Watches are used to recognizes everyday performed hand-gestures [8] or hand- and head-movements to control an intelligent desk [38] in the office. First intelligent office furniture which used gesture control[1] reached the market. Additionally, there is an ongoing involved of NUI by the entertainment industry for designing input technologies (e.g. controller for games consoles like Nintendo Wii, Microsoft Kinect, etc.).

Paradoxically, NUI targets at an improved use of physical strength and reduction of mental effort while learning these interaction techniques by drawing on previous experience and trained gestures, but produces at the same time new challenges for people with mental and physical disabilities because of the variety of required body movements and the involvement of different body parts in space. This include static disabilities as well as temporary disabilities in the rehab field. Therefore, novel adaptive and normalized NUI interaction technologies are required [33, 45].

In the area of traditional input-devices a variety of special devices esp. for people with physical limitations were developed, e.g. oversized trackball-mice or adaptive keyboards with special mechanics for supporting users with uncontrollable muscle movements and gross sensory motor skills (tremor) [41]. However, several studies report the insufficient acceptance and application of such devices [21].

In order to design future intelligent environments and interactive cyber-phyiscal spaces an universal approach („universal design" or „design-for-all") is needed, which includes people with different physical, cognitive and social conditions [42]. Yee [45] suggests a a series of parameters, which should be considered by choosing interaction techniques: physical abilities, controlled motor skills (e.g. fine motor skills, operating range, strength, fatigue, and the ability of contemporary movements) cognitive abilities, sensorial capacities, personal preferences, environmental conditions, involved processes, temporal aspects, financial terms, portability, and normalization. A series of studies focusses on aspects of physical disabilities and the design of interaction techniques. Examples include

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[1] http://www.misterbrightlight.com/

the project SINA [45], where camera-based techniques are used and one project which uses the EU ICT-strategy [6] for designing easy to use interfaces in changing environments. Other projects address the design of age-appropriate products, the usage of touch-screens in care, etc.

In the majority of publications in that area, it is mentioned, that a unified and stringent method for the universal design of interaction is not yet available. Current research activities are mostly focussing either on the user in general or limiting to laboratory tests with very dedicated basic conditions [33]. Anthony et al. [3] are reporting in their actual study, that the usability of touchscreen-based interactions for people with visual impairments is better investigated than for people with motor skills deficits. At the same time the use of motion-based gesture control by means of NUI in regard of controlled rehabilitation beyond clinical environments is also an area of active research. Within the scope of serious games, Huang et al. [20] use the Microsoft Kinect for recognizing movements of rehabilitation exercises of patients suffering from cerebral movement disorders. Butler et al. [9] utilize the Nintendo Wii for controlled rehabilitation. That interaction technique is increasingly utilized outside the hospital in order to keep up the patients motivation. First industrial solutions in that area are available[2]. Schätzlein et al. [37] on the other hand developed a glove for users with restricted mobility, which acts as a movement support according to rehabilitation while gaming. In total all these solutions rely on a playful component, but are less focussed on everyday environments. Current research projects such as SiRIA[3] investigate in this connection how the integration of such exercises in everyday tasks and movements is possible using embedded sensors.

A.1.1. Interaction Ensembles

Interaction Ensembles is a novel approach for anthropometric optimized interaction techniques. Main idea is the configuration of interaction modalities and devices at runtime of an application as well as optimizing the entire interactive system regarding (1) the users' physical disabilities — anthropometric profile, (2) the requirements of a particular application — interaction profile, and (3) the usage context. Precondition of such a system is the modularization of interaction techniques and realization as autonomous encapsulated, exchangeable, adaptive, and combinable units [1, 2]. By means of the automatic configuration of interaction devices and their interconnection in a network („Interaction Ensembles") the whole system is optimally adapted to the users and the context and not the reverse.

For the realization of such a concept, we are currently developing the STAGE-framework, based on a software-platform (Ambient Dynamix [12]) for recognizing and processing contexts on mobile devices (currently Android-based Smartphones of tablets) which was likewise developed at our institute. Mobile devices provide optimal basis for that project,

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[2] http://www.gesturetekhealth.com/products-rehab-irex.php

[3] http://projekt-siria.de/

because they are mostly available, avoiding complex instrumentalization of different user environments, and considers privacy aspects and the autonomous control of users. A mobile STAGE-device holds a profile corresponding to the previous defined requirements (1) and (2) ready and configures the devices in-situ in respect of the particular specific usage context (3).

A.1.2. User-defined gestures

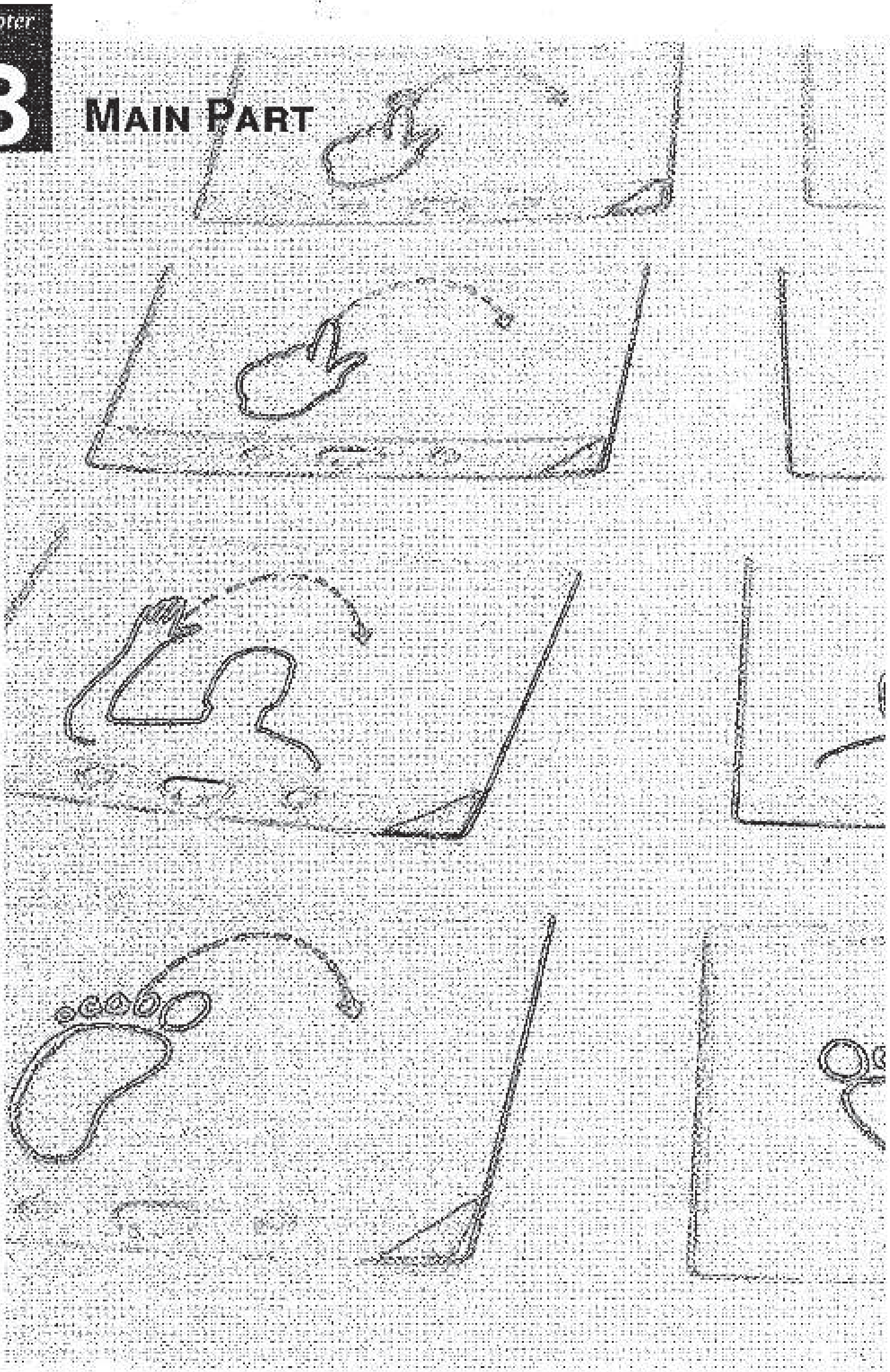
Due to the increasing use of gestures to control devices and the absence of a standardized gesture-alphabet, so called Guessabilitiy-studies [43] were used as an instrument for eliciting user-defined gestures for controlling systems. Cafaro et al. [10] are describing these studies as a Bottom-Up-methodology in which users see a system reaction. Afterwards they have the possibility to guess a gesture which might cause that system reaction. All gestures are collected and an agreement among all test persons for a single system reaction is determined. In comparison, the Top-Down-methodology describes the definition of gesture sets done by the respective device manufacturer. Nacenta et al. [33] evaluated the memorability of such user-defined gestures in comparison with pre-defined gesture sets. They found, that user-defined gesture are faster and better memorized than pre-defined sets. Nevertheless, the methodology of guessability studies is a subject of controversial discussion, because users are often biased by previous experiences with common interactive systems and relating these knowledge directly to such studies [29]. Moreover, the age of users [23] as well as cultural influences [27] may lead to different results. Due to these resasons guessability studies need to planned and performed thoroughly. Choi et al. [14] were able to show, that gestures which had a high agreement among participants while one study will be completely different rated in further studies. Simultaneously, formal methods exists, which clearly show the statistical significance of agreements of elicited user-defined gestures [39].

A.2. Outlook

The remainder of this report is split into 4 chapters. Chapter B gives a general overview about the carried out study. The study-design including the setup, procedure, the volunteer recruitment, and the developed system architecture are presented. Next, the collected data while performing the study is analyzed, diagrammatic presented and wrapped into general observations in chapter B.3. On this basis, the findings are discussed in chapter B.4. Finally, a summary of this report is presented in chapter C.

Chapter

B MAIN PART



B.1. Methods

In this chapter, we discuss all related aspects to the design of a three-fold qualitative and explorative study conducted as part of this project. The study is designed and conducted in three phases:

Phase 1 "Guessability Study with healthy participants (Kohorte 1)" aims at investigating the users' interaction behavior with typical smart devices in office environments (e.g., telephone, printers, window, light, etc) in the case of simulated physical impairments (focused on limited arm and hand physical capabilities).

Phase 2 "Guessability Study with impaired participants (Kohorte 2)" that study aims at investigating the users' interaction behavior and interaction strategies with typical smart devices in office environments in the case of physical impairments related to arm and hand.

Phase 3 "Wizard of Oz with impaired participants (Kohorte 3)" evaluating and analyzing the use of a number of realistic Interaction Ensembles scenarios in office environment.

B.1.1. Guessability Study — Referents and Office Setup (Phase 1 and Phase 2)

As introduced earlier, this study is mainly focused on office environment as application domain. We have analyzed different office related scenarios in order to identify possible referents (i.e., tasks) that are of interest to the study. Initially, we have identified 56 referents split into 30 surface and 26 ambient tasks. Surface referents are tasks that take place on either horizontal or vertical surfaces in the office, for example wiping content on a smart wall or desk. Ambient referents are tasks that are not bound to a particular surface such as the room's light or temperature.

In order to limitate the study to a manageable and realistic time duration, we have decided to constrain the study to 27 referents split into 12 surface and 15 ambient office referents (shown in Table B.1). However, the original referent coding was kept including its numbering. We have equipped a room with a basic office layout and the needed smart devices for the experiment. The devices included smart RGB light (a strip with 300 programmable LEDs based on the Art-Net protocol), a simulated window blind projected on a wall (building and integrating a real controllable window blind in the hospital was not possible), smart telephone (a normal office phone equipped with an extra screen), smart printer (laserjet printer equipped with an extra screen), smart table (normal table with top projection), and smart wall (wall projection). Each device is responsible for demonstrating (i.e., showing) the referents attached to the device as shown in Table B.1. The actual placement and positioning of those devices in the office is should in Figure B.1 and Figure B.2. The devices can be all individually controlled remotely from a central base controller. The controller is responsible from generating the order of the experiment for each participant. The controller is then used by one researcher to control the experiment flow as discussed in section B.1.2. The technical setup and implementation of those devices are discussed in section B.1.1.1.

In addition, one part of the room, equipped with an extra table, was dedicated for documentation and observations. Moreover, two video cameras were positioned to capture the full movements of the participant body and the interactions to capture the upper and lower parts of the participant's body.

Table B.1.: Referents Considered for the Guessability Study (Phase 1 and Phase 2)

Object/Artifact	**Referents**	
	Code	**Description**
Smart Blind	B1	Open Window Blind
	B2	Close Window Blind
Smart Telephone	T1	Accept Call
	T2	Reject Call
	T3	Change Contact
	T5	Increase Volume
	T6	Decrease Volume
Smart Table	D1	Delete an Object
	D2	Accept Action
	D3	Reject Action
	D4	Change Background
	D6	Zoom In
	D7	Zoom Out
Smart Wall	W1	Delete an Object
	W2	Accept Action
	W3	Reject Action
	W4	Change Background
	W6	Zoom In
	W7	Zoom Out
Smart Printer	P1	Turn On
	P2	Turn Off
	P5	Delete Job
Smart Light	L1	Turn On
	L2	Turn Off
	L3	Change Color
	L5	Increase Intensity
	L6	Decrease Intensity

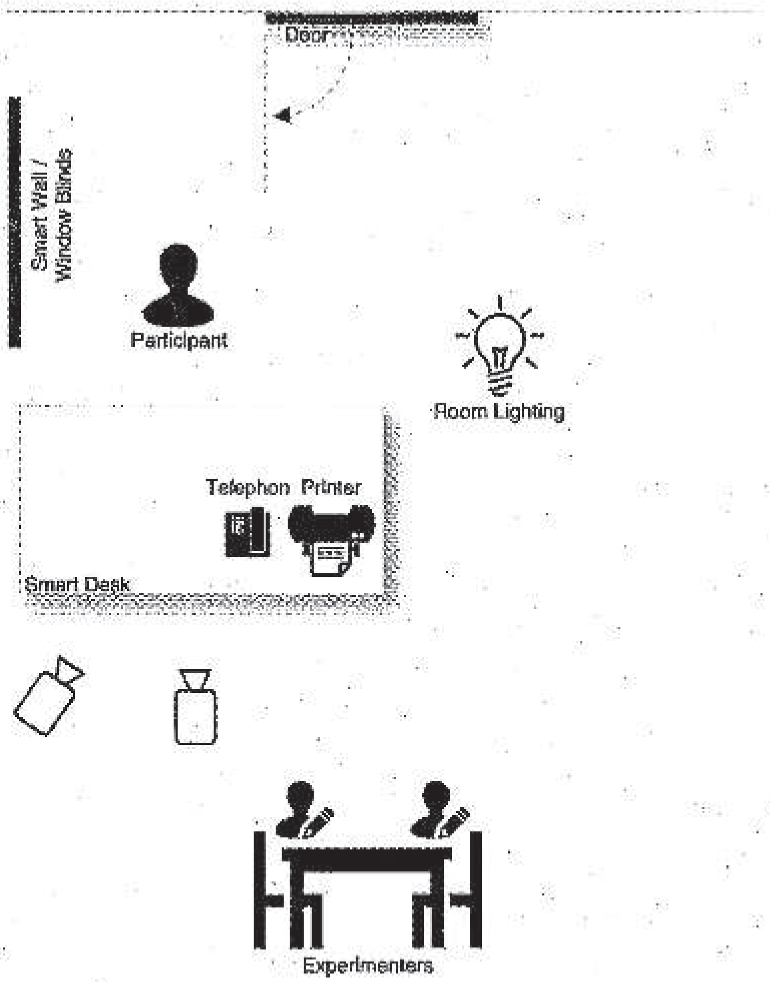


Figure B.1.: Office Setup Used for Phase 1 and 2 (Outline)

B.1.1.1. System Architecture

To provide a realistic office setup and efficiently collecting data while carrying out the study, we've built a distributed system architecture with a single controller node. As depicted in Figure B.3, our architecture involves three main layers, following a slightly adapted *Model-View-Presenter*-Pattern [24] for distributed devices in explorative studies.

Each devices' graphical user interface was developed as an HTML-page using JavaScript and jQuery[1] as a framework for animations mimicking real system reactions, following the responsibility as a passive view. Because of the heterogeneity of operating systems running on different devices, we targeted to develop using platform-independent and

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[1] http://jquery.com/

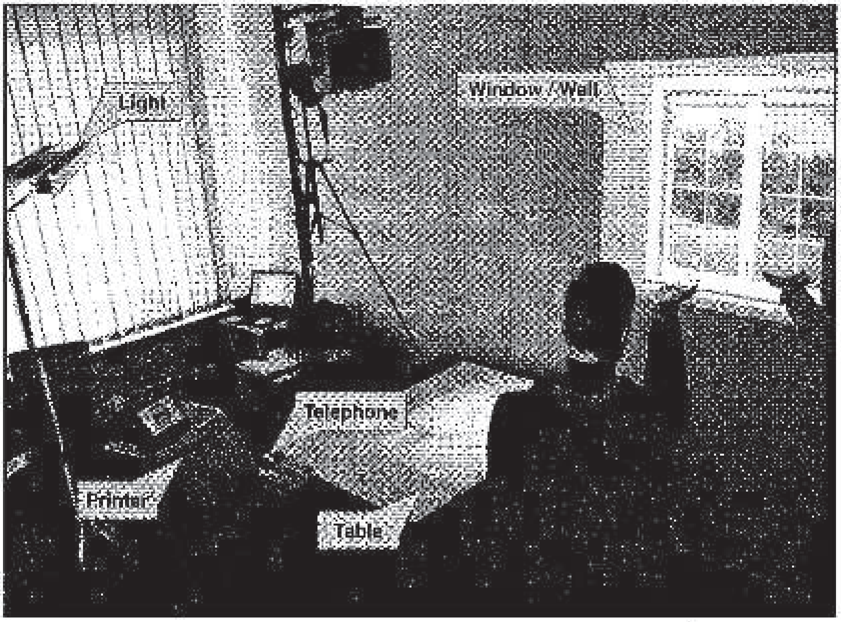

Figure B.2.: Office Setup Used for Phase 1 and 2

fast deployable technologies. All graphical users interfaces including the controller were provided by the web-server, located in the model-layer, which additionally works as a mediation layer between view and presenter. Each device, listed in Table B.1 was accessing its UI by simply using a Web-Browser like Firefox or Chrome. Once the page is opened, the device subscribes itself to the WebSocket-server, using the WebSocket protocol [15] and listening on further commands.

Similarly the controller, located in the presenter-layer, registers itself to the WebSocket-server. Additionally, the WebSocket-server generates a unique ID, based on previous persisted datasets located in a local database at the model-layer, which is used as a reference for further processing. Moreover, the controller consists of four main building blocks, which are described in the following:

Sequence Control Unit is responsible for generating and observing the sequence of referents and devices within one experiment round. First of all, the order of devices are determined, followed by the referents associated to each device. It is important to mention, that complementary referents are consecutively ordered.

Bodypart Picker In order to provide an easy possibility to capture used body parts of a user-defined gesture, the controlling experimenter has the possibility to insert these information by using a visual Bodypart Picker.

System Reaction Trigger The System Reaction Trigger is responsible to command each device to execute the needed system reaction. Moreover, each device state can be modified and therefore any system reaction can be triggered again at the desire of the participant.

Round Evaluation Unit Beside of capturing execution- and thinking-times, the Round Evaluation Unit is responsible for persisting given answers of questions asked after the execution of a gesture.

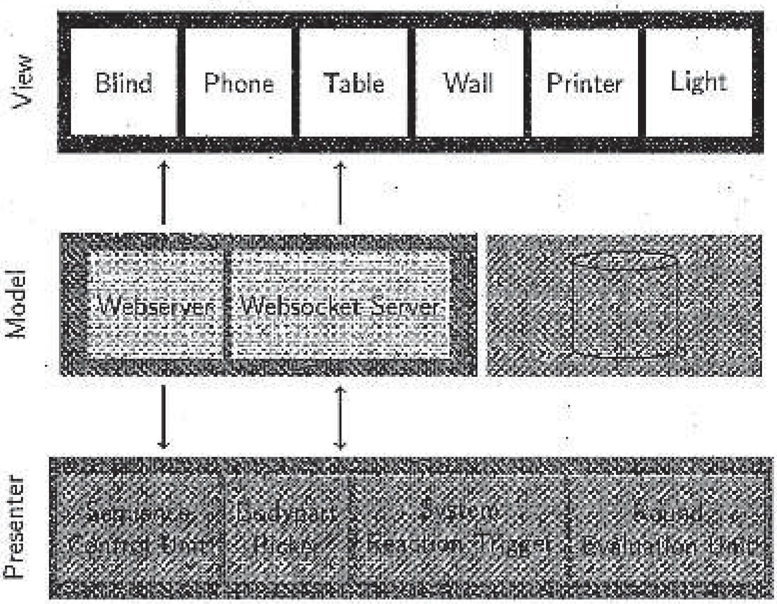

Figure B.3.: System-Architecture Phase 1 & 2

B.1.2. Guessability Study — Study Procedure (Phase 1 and Phase 2)

Phase 1 and 2 were independently conducted in Lübeck and Bad Bramstedt. However, they followed the same order of study, which splits into five different steps:

- Welcome and introduction
- Pre-questionnaire
- Experimental rounds — level 1 (no imposed restrictions)
- Experimental rounds — level 2 (imposed restrictions)
- Semi-Structured interview

B.1.2.1. Volunteer recruitment

The preparation for conducting phase 1 was initiated by starting the hiring process for healthy volunteers. The hiring process was based on a public call for volunteering, which was distributed amongst different mailing lists related to the University of Lübeck and through local social networks at the city of Lübeck, Germany. The call for participation can be found in Appendix I. The targeted number of participants in this phase was set to 16 participants. Hence, it was planned to hire 20 participants with a possible drop rate of 25%.

The participants acquisition for Phase 2 was conducted by our project partner at the Bad Bramstedt hospital[2]. Another three participants were recruited by the Rheuma-Liga Schleswig-Holstein e.V. — Ortsgruppe Ratzeburg[3]. The target number of participants was set similar to Phase 1.

In total we were able to recruit 20 participants for Phase 1 and 13 for Phase 2. A more detailed description of the group of participants will be presented later in this document (see section B.3.1).

B.1.2.2. Welcome and introduction

On the day of the experiment, participants were received and welcomed at the study location and introduced to the study general procedure. The introduction mainly highlighted that (1) the office is smart and is able to sense all user actions, (2) the office has 6 smart devices that the participant will interact with, (3) the participant should use motion gestures to control the referents associated with the devices, and (4) no touch-enabled device is available.

The participants were also provided with a information sheet about the study (found in Appendix II) and were then asked to sign a consent form to conduct and film the experiments (found in Appendix III).

B.1.2.3. Pre-questionnaire

We aimed by the questionnaire to collect some information about the participant's background. We were mainly interested to acquire general information about the participant's age, gender, profession, physical status (dominant hand and physical limitations/impairments), experience with multitouch gestures (how often he/she uses multitouch

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[2] Dr. med. Andreas Christoph Arlt, Klinikum Bad Bramstedt, Ärztlicher Direktor der Rehabilitationsklinik, Leitender Arzt der Klinik für Neurologische Rehabilitation, Facharzt für Neurologie, Facharzt für Physikalische und Rehabilitative Medizin.

[3] https://rlsh.de/ortsgruppen/ortsgruppe-ratzeburg/

gestures), experience with motion gestures (how often he/she uses motion gestures), and experience with office tasks (how often he/she works/used to work in an office). The participants were asked to rate how often the three experience questions on scale from (0: Never to 7: very often). The full questioner can be found in Appendix IV.

B.1.2.4. Experimental rounds — level 1 (no imposed restrictions)

In this part of the study, the participant was asked to define motion gestures for 27 referents in 27 individual rounds. At this stage no physical restrictions were imposed. For each round the following procedure was adopted: (1) the office was prepared by setting all devices and artifacts to initial status, (2) the referent was introduced (the order of referents and devices were randomised), (3) the referent was executed (i.e., demonstrated) in order to reduce the participants' subsequent cognitive load and give them the possibility to built up a mental model of how the system works, (4) the participant was asked to think about an appropriate gesture for the referent (Think-aloud protocol was recommended), (5) the participant was asked to perform the gesture (starting the execution by verbally saying START and finishing the gesture by saying STOP), and finally (6) the participant was then asked to evaluate the selected gesture. The evaluation for each round was based on rating three questions (1: very good, 5; very bad): "Was it easy to think about the gesture?", "Was it easy to execute the gesture?" and "Does the gesture fits the task?"

For each of the performed rounds, the experimenters recorded the body parts used, the thinking time and the execution time.

For reasons of documentation the whole study progress was recorded on video. Two video cameras were positioned to capture the full movements of the participant body and the interactions with the 6 objects. The videos were later manually annotated by two individual researchers using ANVIL [22] — a software for analyzing annotating videos, based on previously defined formalized criteria. We've analyzed the videos regarding the following criteria:

- Thinking time duration
- Execution time duration
- Gesture type
- Gesture meaning
- Gesture description
- Temporality (discrete vs. continuous)
- Relation to other gestures (similarity vs. complementary)

All information, gathered by annotating the videos, were transferred into a relational database for further investigation. Based on these data, large part of the following findings were generated. Additional findings were generated by conducted semi-structured interviews. A more detailed discussion about the interviews can be found hereinafter.

B.1.2.5. Experimental rounds — level 2 (with imposed restrictions)

Similar to the first experimental rounds, the participant was asked to define motion gestures for 27 referents in 27 individual rounds. Nonetheless, we have restricted the use of arms and hands in at this stage of the study. Participants were asked and continuously reminded that it is no possible to use their hands and arms for this part of the study. Apart of the imposed restrictions, the rest of this stage is identical to the previous rounds.

B.1.2.6. Semi-Structured Interview

In the final part of our Guessability study a semi-structured interview [26, p. 62ff.] was carried out. Each participant was asked to answer questions from three different categories, namely strategy, acceptance, and healthy working, in relation to the previously study phase. In order to deepen the discussion, a number of further questions for each category was asked to probe each participants opinion. The interview was led by one experimenter and documented by a second interviewer. Additionally, the interview was also filmed for record keeping and insuring that all parts of the interview can be documented.

Firstly, we aimed to identify the participant's strategy to define the gestures selected for referents. Hence, the primary question for part of the interview was "How did you choose/select your gestures, did you have a particular strategy?". This question was split into six subquestions: "Did you look for complexity/simplicity?", "Did you look for innovation and novelty?", "Did you look for quick and simple mapping?", "Were you influenced by your previous experience with touch interfaces?", "Do you like to customise gestures yourself? Why?", and "Would you rather prefer fixed gestures? Why?".

Secondly, we aimed to identify the acceptance of using full-body motion gestures in office. The primary question for part of the interview was "How acceptable is the idea of using full-body motion gestures in offices?". This question was split into two subquestions: "Would you use your full body as an interaction medium with your smart office? Why?" and "Do you think it is useful for all office tasks? Why?".

Thirdly, we aimed to identify the potential of using full-body motion gestures for a healthier office. The primary question for part of the interview was "Do you see the potential for using whole body gestures for a healthier office and work style?". This question was split into two subquestions: "Can you imagine using the office as a training environment? Why?" and "Do you think that this may affect your concentration and productivity? Why?".

B.1.3. Feasibility Study "Wizard of Oz" — Referents and Office Setup (Phase 3)

We have aimed in the third part of our study to expose the participants to a number of realistic possible Ensembles in office related tasks. Hence, we have analyzed typical office tasks and related gestures in order to identify a variety of possible real ensemble configurations, mainly with the aid of Phase 1 and 2. Different from Phase 1 and 2, this phase of the study was based on the "Wizard of Oz" approach [17, p 204], which is aimed to provide the participants at a realistic experience with Ensembles. To stimulate this experience, we have equipped the room with a fake smart desk (top projection on a table equipped with various dummy visible interaction sensors). This desk was presented to the participants as a fully functional prototype of an interactive smart desk to gain a maximum realistic interaction experience without technical limitations or obstacles. A dedicated researcher was responsible for simulating any valid interaction with the desk using a remote controller to guarantee reasonable reaction and responsiveness to participants' interactions with the desk. In fact, some participants intentionally tried to trick and fool the system to evaluate its responsiveness and accuracy. Due to the constrained timing of our impaired participants at the hospital, we have constrained this part of the study to two typical gestures (namely, zoom and rotation) and a maximum time of 40 minutes. Each gesture requires the involvement of two body parts and was used in 16 different ensemble configurations with the following sequence:

- 6 different Ensembles (device/modality configurations) for enlarging a picture using the pinch to zoom gesture in single-user and collaborative settings. In terms of collaboration the bodyparts resp. techniques were split between the participant and one experimenter. The split interaction was executed simultaneously. The first round for each settings was allocated as an introductory training round.
- 2 self-created/customized Ensembles for zoom gesture in single-user and collaborative settings. Each participant was asked to chose and perform an Interaction Ensemble consisting of two body parts and associated interaction techniques from a given set. In collaboration, the participants decided which bodypart they want to use and which the experimenter should use.
- 6 different Ensembles for rotation a picture using the rotation gesture in single-user and collaborative settings. In terms of collaboration the split interaction was executed sequentially. The first round for each settings was allocated as an introductory training round.

- 2 self-created/customized Ensembles for rotation gesture in single-user and collaborative settings.

B.1.3.1. System Architecture

Because of the modular design of the system architecture used in phase 1 and 2 (see Subsection B.1.1.1), we easily were able to adapt the previously used setup to the feasibility study. Beside a new graphical user interface to display the system reaction, major changes were done within the controller. In order to enable the controlling experimenter to emulate the system reaction based on the users movements, the devices' UI was also integrated into the controllers UI (see Figure B.4). The communication stack works as described previously.

Event Processing Unit The Event Processing Unit recognizes the touch-events at the controller and passes them through to the tabletop device, where they are processed and converted into an appropriate system reaction. Due to the fact, that current browsers are not reliably able to recognize touch events in a performant way, we used Hammer.js[4].

Round Evaluation Unit The Round Evaluation Unit works as described in Subsection B.1.1.1.

Task Change Trigger In order to change the task without touching the displaying devices, the Task Change Trigger is able remote control the displayed task at the tabletop device.

B.1.4. Ensemble Configurations

The different ensemble configurations are carefully selected based on four ensemble design and assessment factors, namely collaborativeness, hybridity, ensemble size, and body heterogeneity. Table B.2 contains the different ensemble configurations used in this phase of the study.

B.1.4.1. Collaborativeness

Collaborativeness manifests mainly the social setup, in terms of the number of users involved in the interaction. Collaborative spaces have opened great chances for new collaboration habits and patterns for users in offices, museums, exhibition halls, etc. While various researchers study these spaces in terms of the tasks in hand (e.g., collaborative document editing and collaborative games), we focus here on the interaction itself (referred to herein as Collaborative Interactions). Collaborative interaction opens up an interesting scope for NUI, because it breaks the conventional interactivity norms.

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[4] http://hammerjs.github.io/

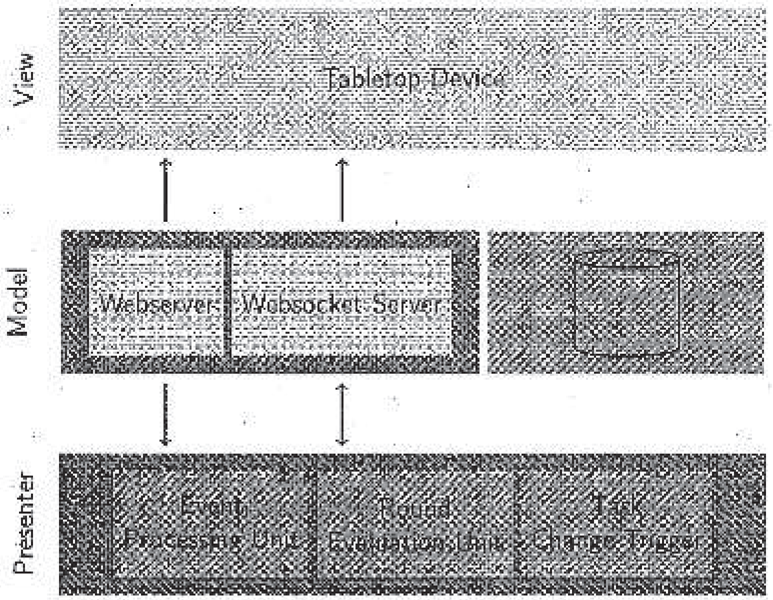

Figure B.4.: System-Architecture Phase 3

Collaborative interaction allows to extend the interaction capabilities by employing extended list of body parts (based on the number of collaborators) to using more than two hands, more than 10 fingers, etc. Hence, new interaction possibilities and patterns can be created to enhance the interaction space.

To our best knowledge, most published research about interacting collaboratively focus on isolated cooperative gestures. Large number of research projects are coined around tabletops [30], collaborative user art performances [30] (multiple users interact to establish a music or entertainment effect), ad-hoc network connections as in SyncTap [35] and Stitching [18] (establish connection between multiple devices through synchronized action), and socialization (e.g., systems for creating stories for children as in StoryTable [11]).

Nonetheless, very little research is done on collaborative interactions in their true sense (i.e., multiple users performing a joined interaction collaboratively). Perhaps some of the earliest examples on this form of interaction are covered in Morris et al. [30].

In their paper, they have presented a number of collaborative gesture scenarios including: enlarge photos (multiple users drag the edges of a photo to increase its size), neaten photos (neatening photos into orderly piles by placing the edges of both hands on the surface of the table, and sweeping them toward each other), photo passing (pass a photo over a large distance by throwing and pulling, one user performs the throwing and another one the receiving part of the gesture), stroke erasure (collaborative rubbing to erase content), and exiting/closing (hold hands, and then one member of the chain touches the table's surface with a single finger).

Code	Task	Techniques	Bodyparts Heterogeneity	Collaboration	Size	Hybridity
Z0	Intro: Zoom picture	Touch	1 (Finger)	1	1	1
Z1	Zoom picture	Touch / Motion	1 (Finger)	1	2	2
Z2	Zoom picture	Touch / Motion	2 (Finger / Foot)	1	2	2
Z3	Zoom picture	Free choice	—	1	—	—
Z4	Zoom picture	Touch	1 (Finger)	2	2	1
Z5	Zoom picture	Touch / Motion	1 (Finger)	2	2	2
Z6	Zoom picture	Motion	2 (Arm / Foot)	2	2	2
Z7	Zoom picture	Free choice	—	2	—	—
R0	Intro: Rotate picture	Touch	1 (Finger)	1	1	1
R1	Rotate picture	Touch / Motion	1 (Finger)	1	2	2
R2	Rotate picture	Motion	2 (Foot / Head)	1	2	2
R3	Rotate picture	Free choice	—	1	—	—
R4	Rotate picture	Motion	1 (Finger)	2	2	1
R5	Rotate picture	Touch / Motion	1 (Finger)	2	2	2
R6	Rotate picture	Motion	2 (Foot / Head)	2	2	2
R7	Rotate picture	Free choice	—	2	—	—

Table B.2.: List of modalities used as Ensemble-Configurations for the Wizard of Oz Study (Phase 3)

According to Morris et al. [30], collaborative gestures are very useful for increasing participation, awareness of important events, reach large surfaces, access control, and entertainment.

B.1.4.2. Hybridity — Hybrid Interactions

New studies and some commercial products have shown the importance of interweaving different types of gestures especially for handheld devices. Chen et al. [13] have proposed to interweave touch and in-air gestures as a unified interaction modality for enhanced and greater expressiveness. While touch gestures may be overloaded in time, space and configuration, in-air gestures suffer from segmentation accuracy. Hence, they have proposed the synthesis of the two input modalities into one to achieve interaction richness and robustness. They have proposed a number of examples such as circle-in-air and tap an icon to trigger a context menu, finger high jump between two taps to select a region of text, and tap and cycle the finger in air to continuously zoom a map. Similarly, the Motion+Touch project [19] combined touch and motion sensing capabilities for touch-enhanced motion gestures and motion-enhanced touch on mobile devices. Recently, some commercial handheld devices (e.g., Galaxy S5[5]) partially support in-air technologies such as hovering, which indicates for many researchers that interweaving touch and motion modalities may be adopted more widely in the near future [13]. The code space project [8] combines touch and in-air modalities for gesturing to support developer meetings. This combination allows users to interact remotely with a display by an in-air pointing and object on-screen touching gesture. Other examples include: manipulating with arm, pointing and manipulating with arm and phone touch, annotating temporarily with arm pointing and phone touch, and object transfer with pointing and touch gestires. The Hand-On Math project [46] explored concurrent touch and pen on one device. Liang et al. [24] investigated user-defined gestures for surface and motion gesturers for manipulating 3D objects at distance through mobile devices. They argued that combining various input capabilities, supported by mobile devices, enables a more expressive and rich set of gestural language for enhancing interaction with mobile devices. One of the oldest HCI explorative project for interweaving interaction modalities is Put-that-there [7] that combined arm tracking with speech recognition in a smart room scenario.

We strongly believe that interweaving interaction modalities will also emerge in various interaction paradigms such as tabletops, tangible interactions, and ambient interactions. Hence, Ensembles may greatly support complex scenarios where multiple interaction modalities are interviewed together. New novel gestures may consist of touch and motion components, for instance a pinch-to-zoom gesture may consist of one in-air motion component for the right arm and touch component for the left arm.

B.1.4.3. Ensemble Size

Ensemble size indicates the number of interaction techniques actively involved to compose a given Ensemble. The increase of the Ensemble size indicates increasing complexity of that Ensemble. In collaborative scenarios, the size is often proportional to the number of users involved in the interaction.

B.1.4.4. Body Heterogeneity

This factor indicates the heterogeneity degree of used body parts in an Ensemble. With the tendency to move towards full body in motion, more body parts will be involved in the interaction. Similarly, Ensembles are expected to involve various body parts. Users interacting within one Ensemble may have similar interaction tasks but use different modality and different body parts as part of the interaction. The increasing heterogeneity of body parts adds to the complexity of the Ensemble building and execution.

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[5] http://www.samsung.com/de/consumer/mobile-device/smartphone/smartphone/SM-G900FZWADBT

B.1.4.5. Office Setup

The office setup and the distribution of devices used are illustrated in Figure B.5 and Figure B.6. For this part of the study, we have equipped the room with a simulated smart desk/table (normal table with top projection). Various dummy interaction sensors were placed on the table for assuring participants about the smartness and capabilities of the table. The table was split into three main areas: (1) interaction area where the interaction with actual referent takes place, (2) modality cards where different interaction modalities can be selected to configure the table interaction capabilities and (3) activation area where the modality cards should be placed to activate the actual table sensing capabilities. The interaction area and its reaction to the participant actions were controlled remotely by one of the experimenters without any notice from the participant. In addition, one part of the room, equipped with an extra table, was dedicated for documentation and observations. Moreover, one video camera was positioned to capture all experimental sessions for record keeping purposes and for later analysis.

B.1.5. Wizard of Oz Study — Study Procedure (Phase 3)

- Welcome and introduction
- Pre-questionnaire
- Experimental rounds — Zoom gesture
- Experimental rounds — Rotation gesture
- Semi-Structured interview

B.1.5.1. Volunteer recruitment

The participants acquisition for Phase 3 was conducted by our project partner at the Bad Bramstedt hospital[6]. Our target number of participants was set similar to 20 participants with a tolerated drop rate of 25%.

In total we were able to recruit 21 for Phase 3. A more detailed description of the group of participants will be presented later in this document (section B.3.2).

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[6] Dr. med. Jochen Steinmetz Leitender Oberarzt der Klinik für Neurologische Rehabilitation Facharzt für Neurologie, Physikalische Therapie, Sozialmedizin, Rehabilitationswesen.

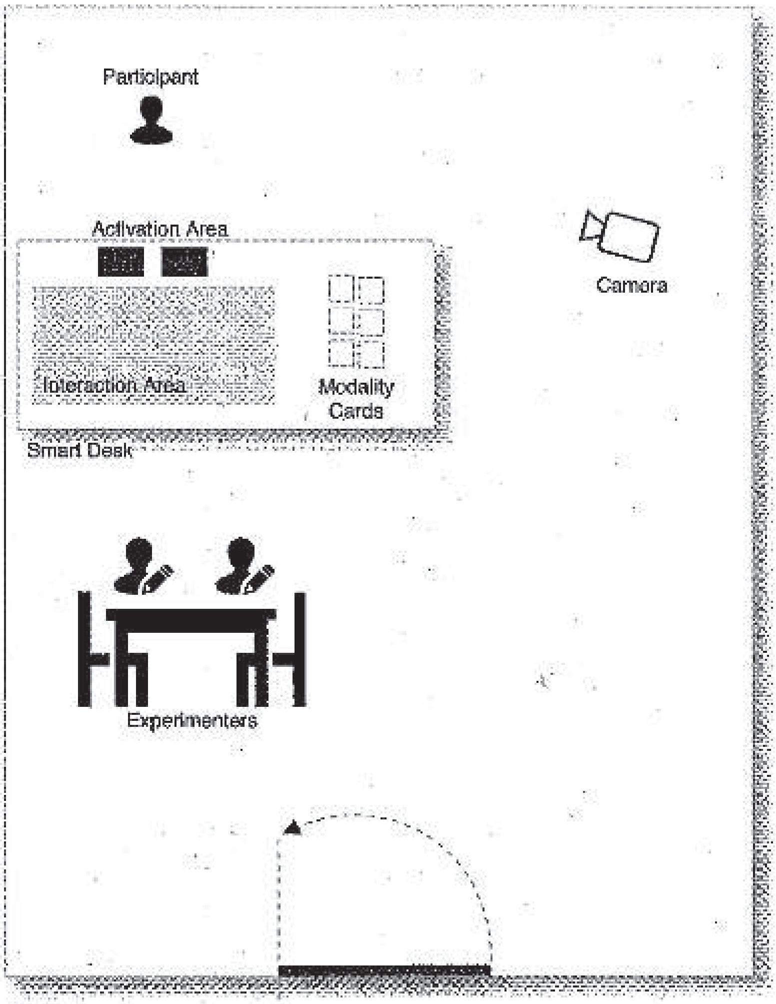


Figure B.5.: Office Setup Used for Phase 3 (Outline)

B.1.5.2. Welcome and introduction

On the day of the experiment, participants were received and welcomed at the study location and introduced to the study general procedure. The introduction mainly highlighted that (1) the office is smart and is able to sense all user actions, (2) study will be mainly about the office's smart desk, (3) the participant should use touch and motion gestures to perform two tasks, namely zooming and rotation a picture, and (4) the table sensing capabilities should be activated before performing the interaction (by placing the right modality card on the activation area). The participants were also provided with an information sheet about the study (found in Appendix II) and were then asked to sign a consent form to conduct and film the experiments (found in Appendix III).

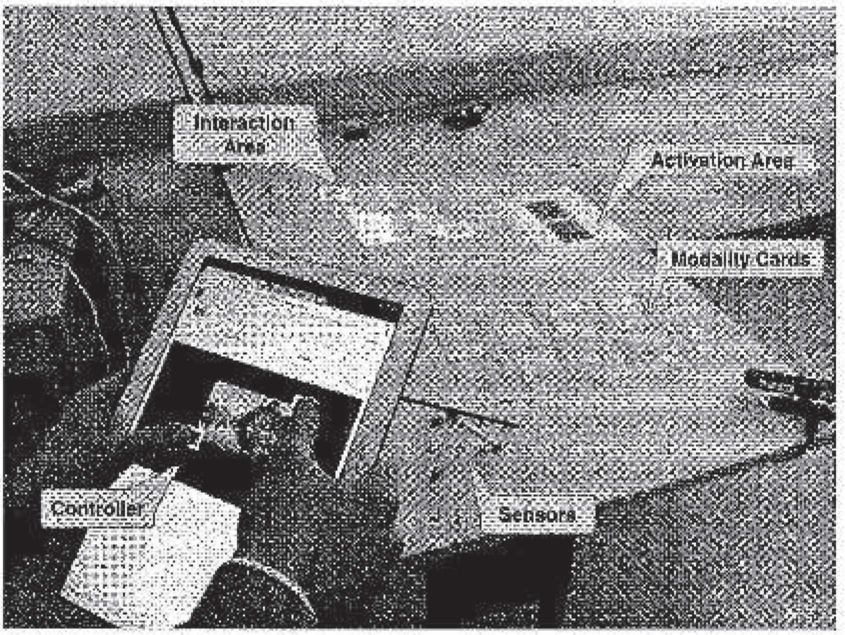


Figure B.6.: Office Setup Used for Phase 3

B.1.5.3. Pre-questionnaire

Similar to the previous two phases, we aimed by using the same questionnaire (Appendix IV) to collect some information about the participant's background.

B.1.5.4. Experimental rounds — Picture Zoom

In this part of the study, the participant was asked to perform a pinch to zoom gesture for enlarging a picture. The participant was presented with different variations (Z0 -Z7) of this gesture as shown in Table B.2 by varying the used modalities for interactions. These experimental rounds were split into single and collaborative settings. Figure B.7 illustrates the different rounds conducted in this phase of the study.

- Introduction round using touch
- 2 different device configurations (single user)
- Free choice
- 3 different device configurations (collaborative)
- Free choice

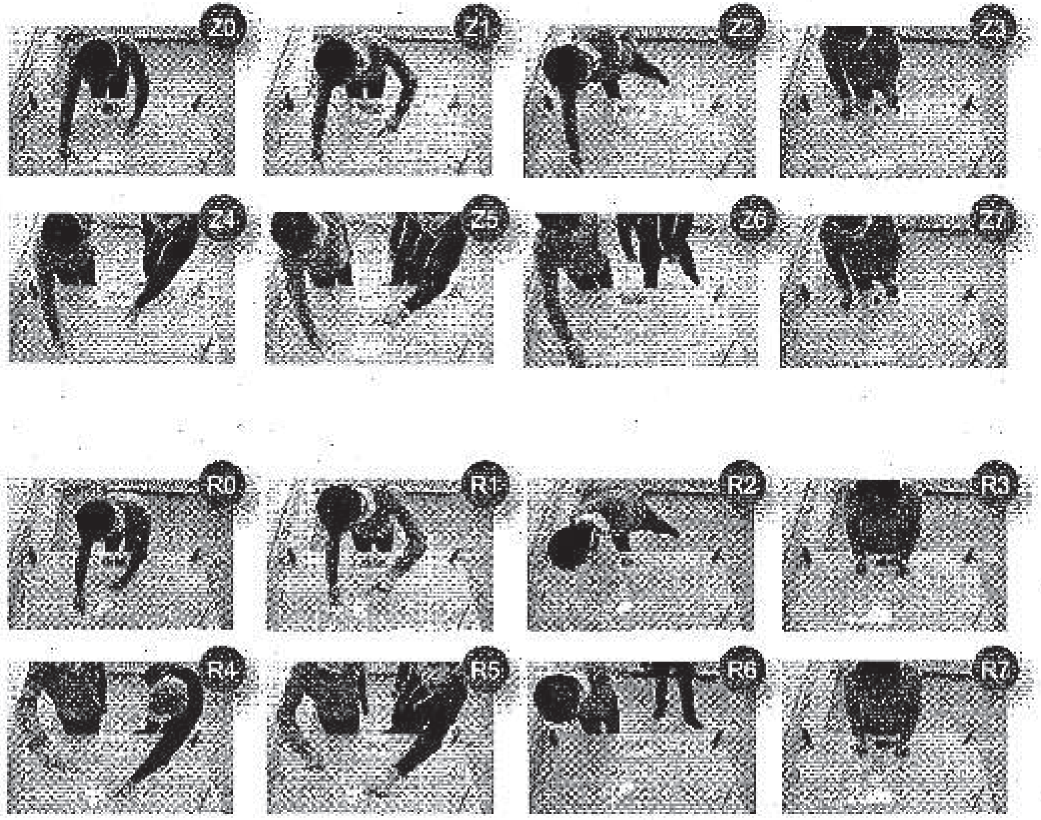


Figure B.7.: Demonstration Rounds (Phase 3)

The first session was planned around single-user settings. The participant was first presented with an introductory training round (Z0). In this round, the participant was asked to perform the pinch to zoom gesture with two fingers on the table (touch). Next, we have increased the modality hybridity by asking the participant to perform the zoom gesture with one finger in the air and one finger touch (Z1). Next, we have increased heterogeneity of the used body parts by asking the participant to perform the gesture with one finger (touch) and one foot (Z2). After the aforementioned rounds, the participant was asked to create/suggest a combination of her/his choice.

The second session was planned around collaborative settings. Firstly, the participant was asked to perform the pinch to zoom gesture with two fingers on the table (touch) jointly in collaboration with another user (i.e., an experimenter) (Z4). Next, we have increased the modality hybridity by asking the participant to perform the zoom gesture with one finger in the air and one finger touch (Z5). Next, we have increased heterogeneity of the used body parts by asking the participant to perform the gesture with one arm (motion) and one foot (Z6). After the aforementioned rounds, the participant was asked to create/suggest a collaborative combination of her/his choice (Z7).

For each of those rounds, we have asked the participant to rate the ensemble on three aspects: effort (Was it easy to execution the proposed gesture?), physical load (Was the task physically easy to perform?) and familiarity (Was the task common or known to you?).

Right after a participant experienced an ensemble, we asked to answer two Likert scale questions. In order to identify the physical and cognitive complexity to execute such ensemble, we asked to answer the question "Was it easy to execution the proposed gesture?" from scale ("1" — very easy to "5" — very difficult). To assist the Ensemble familiarity, we asked to answer the question "Was the task common or known to you?" from scale ("1" — well-known to "5" — widely unknown). A third questions was added in case, that the participant was asked to self defining an Ensemble. The participants were asked to answer the question ("How easy was it to guess these configuration?") on a Likert scale from "1" — very easy to "5" — very difficult in order to find how cognitive demanding a customized Ensemble is.

B.1.5.5. Experimental rounds — Picture Rotation

In this part of the study, the participant was asked to perform a rotation gesture for rotating a picture. The participant was presented with different variations (R0 — R7) of this gesture as shown in Table B.2 by varying the used modalities for interactions. These experimental rounds were split into single and collaborative settings.

The first session was planned around single-user settings. The participant was first presented with an introductory training round (R0). In this round, the participant was asked to perform the rotation gesture with two fingers on the table (touch). Next, we have increased the modality hybridity by asking the participant to rotate the picture with one finger in the air and one finger touch (R1). Next, we have increased heterogeneity of the used body parts by asking the participant to perform the gesture with foot (touch) and head (R2). After the aforementioned rounds, the participant was asked to create/suggest a combination of her/his choice.

The second session was planned around collaborative settings. Firstly, the participant was asked to perform the gesture with two fingers on the table (touch) jointly in collaboration with another user (i.e., an experimenter) (R4). Next, we have increased the modality hybridity by asking the participant to perform the gesture with one finger in the air and one finger touch (R5). Next, we have increased heterogeneity of the used body parts by asking the participant to perform the gesture with one foot and the head (R6). After the aforementioned rounds, the participant was asked to create/suggest a collaborative combination of her/his choice (R7).

B.1.5.6. Semi-Structured Interview

In the final part of this phase of the study a semi-structured interview was carried out. Each participant was asked to answer questions for three different categories, namely strategy, acceptance, and healthy working, in relation to the previously study phase. In order to deepen the discussion, a number of further questions for each category was asked to probe each participants opinion. The interview was led by one experimenter and a second experimenter documented the interviews. Additionally, the interview was also filmed for record keeping and insuring that all parts of the interviews can be documented.

Firstly, we aimed to identify the participant's strategy to create Ensembles. The primary questions for part of the interview was "How Ensembles should be ideally created?" and "Which Ensembles do you prefer the most?". These questions were split into 5 subquestions: "Should Ensembles be complex/simple?", "Should Ensembles be innovate and novel?", "Should Ensembles be influenced by the user's previous/known experiences (e.g., touch interfaces)?", "Should you be able to customizable your own set of Ensembles? Why?", and "How would you customize the ensemble (using the same ensemble, body parts, devices)?".

Secondly, we aimed to identify the acceptability of using Ensembles in office environments. The primary question for part of the interview was "How acceptable is the idea of using interaction Ensembles in offices?". This question was split into two subquestions: "Would you use your full body as an interaction medium with your smart office? Why?" and "Do you think it is useful for all office tasks? Why?".

Thirdly, we aimed to identify the potential of using full-body motion gestures for a healthier office. The primary question in this part of the interview was "Do you see the potential for using whole body gestures for a healthier office and work style?". This question was split into two subquestions: "Can you imagine using the office as a training environment? Why?" and "Do you think that this may affect your concentration and productivity? Why?".

Fourthly, we aimed at identifying the new possibilities that the Ensembles may provide. The primary question in this part of the interview was 'Do Ensembles open new possibilities?". The question was supported by two subquestions: "Do you think of other tasks were Ensembles can be useful?" and "Do Ensembles support your daily life activities? Why?"

Finally, we aimed to identify possible challenges related to the learning and remembering of interaction Ensembles. The primary question in this part was "What do you think about the learning and remembering of interaction Ensembles?". This question was split into five supporting subquestions: "Do you think Ensembles are hard to learn? Why?", "Do you think Ensembles are hard to be remembered? Why?", What are the easiest part of experienced Ensembles during the study?", "What are the hardest part?", and "Do you have any other thoughts to share?".

B.2. Study Execution and Implementation

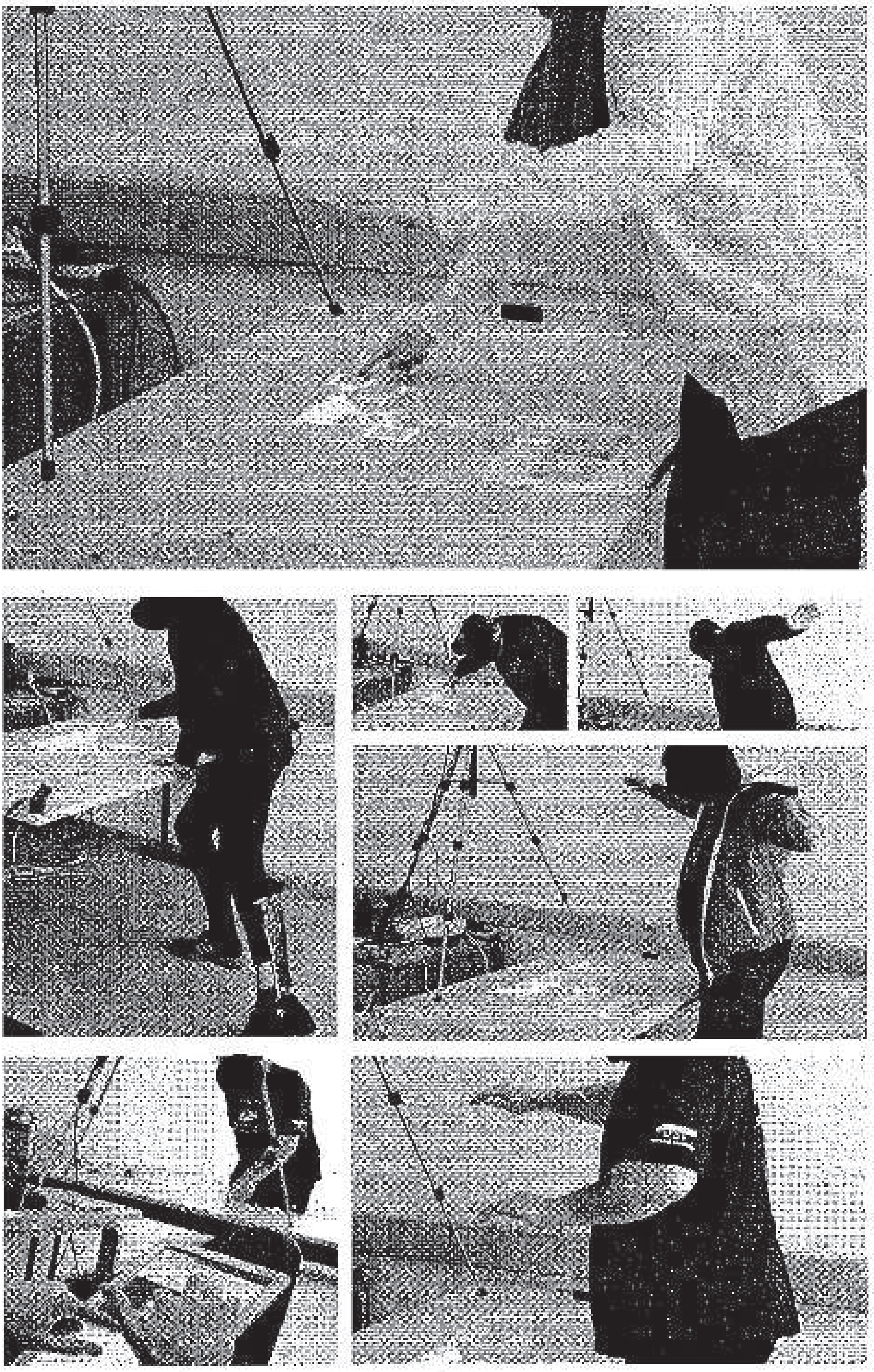
Acquiring participants for the study started in September 2014. For the first acquisition phase 20 healthy participants were selected after an open public call for participation which was open for one week. This number of participants fulfilled our participation target for this phase of the study. The second acquisition phase was conducted in November 2014 by our project collaboration partner in the Bad Bramstedt hospital in Germany. Initially 15 participants were required but only 10 participants were able to attend to our experiment. Hence, we have later acquired two more participants through the Rheuma-Liga Schleswig-Holstein e.V. — Ortsgruppe Ratzeburg. Hence, 20% dropout rate was recorded for this part of the experiment. For the third phase of the study, 20 participants where acquired in April 2015 by our project collaboration partner in the Bad Bramstedt. This number of participants fulfilled our participation target for this phase of the study.

Due to the unexpected absence of our collaboration partner and unexpected temporary shortage of space at the hospital, the third phase of the study was delayed for three months (starting in April instead of January 2015). This has impacted the overall time needed for the project.

Moreover, we have initially planned to use the same participants in phase two and three of the experiment, but due to the aforementioned delay, we had to readjust our plan and to conduct the third phase of the study with new participants. This did not change or impact the results of our study plan. Nonetheless, this has imposed additional effort for acquiring and scheduling new participants which was not anticipated before.

During the experiment we have collected data from multiple resources including video recordings (ca. 70 hours), automatic data logging (ca. 1700 logs), hand-written interview scripts (52 scripts), and hand-written questioners (52 filled forms). The processing of the data from these resources required more time than originally anticipated due to the long time required to code the videos. The delay caused in the execution phases of the study also impacted the processing speed of the videos as the student assistants allocated to this task had to take various university examinations. This delayed the processing of raw data by one month.

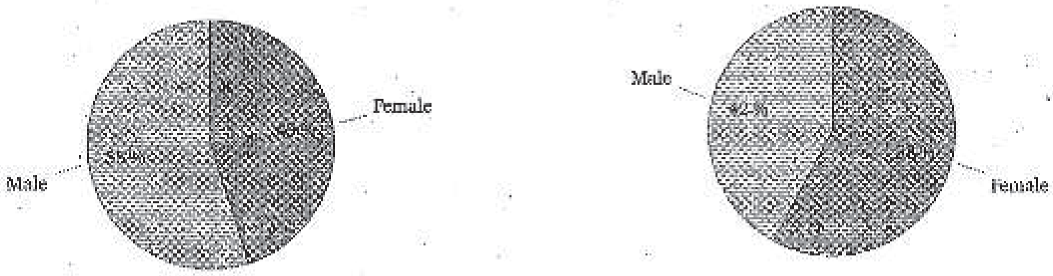
B.3. Results



B.3.1. Guessability Study — Phase 1 and Phase 2

According to the study plan, our Guessability study [48] was split into two phases, namely "Phase 1" for healthy participants and "Phase 2" for participants with physical impairments. In phase 1, we have acquired 20 volunteers to take part in the study. The participants were employed by an open call for participation, which was send to students and employees afflicted with the University of Lübeck, Germany. The participants came from different professional backgrounds including students, project management, system administration, and research assistance. The age of our participants ranged from 21 to 50 years old, with an average age of 27 years old with 55% male and 45% female participants as shown in Figure B.8(a).

In phase 2, we have acquired 12 volunteers to take part in the study, which were directly acquired by the project collaboration partner in the Bad Bramstedt hospital in Germany. The participants came from different professional backgrounds including journalism, administration, marketing, and pensioners. The age of participants ranged from 21 to 71 years old, with an average age of 51 years old with 42% male and 58% female participants as shown in Figure B.8(b).



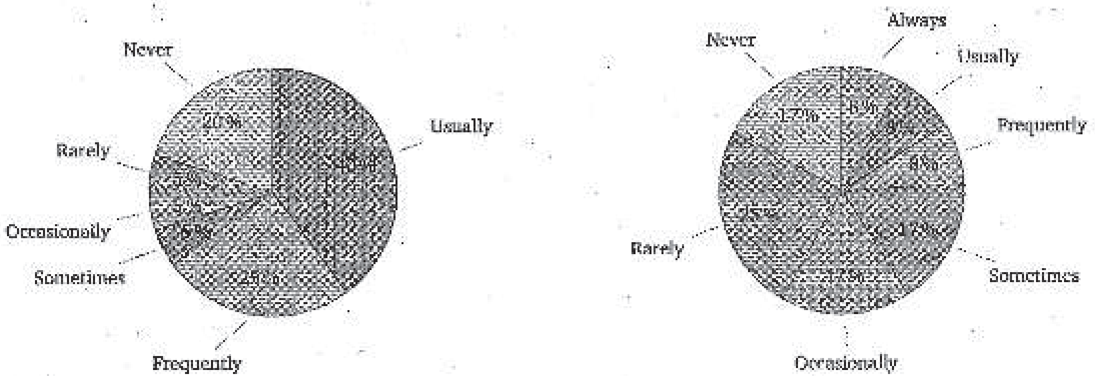
(a) Participants (Phase1)

(b) Participants (Phase2)

Figure B.8.: Participants' gender

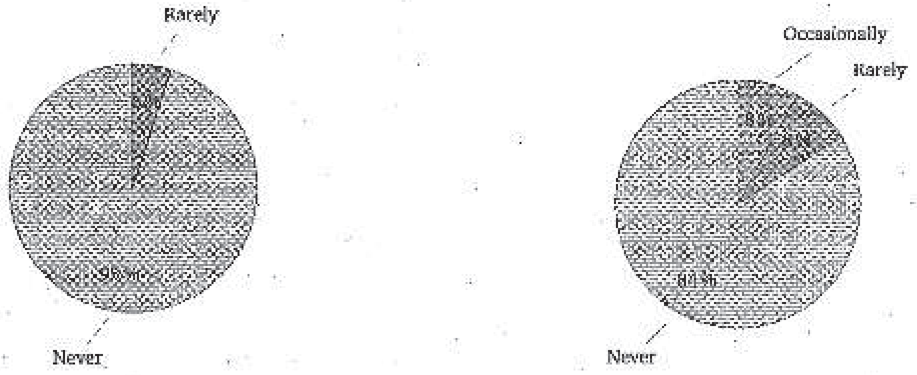
We have used the pre-questionnaire to identify a number of general observation about our participants. The majority of the participants in phase 1 (65%) are more familiar with touch interfaces compared to participants in phase 2 (24%) as illustrated in Figures B.9(a) and B.9(b). Nonetheless, most of the participants in both phases had no experience with motion interfaces as shown in Figure B.9(c) and Figure B.9(d).

The majority of participants in both phases are familiar with office work as illustrated in Figure B.10, merely 20% and 17% of the participants reported no experience with office work for phase 1 and phase 2 respectively.



(a) Familiarity with touch (Phase1)

(b) Familiarity with touch (Phase2)



(c) Familiarity with motion (Phase1)

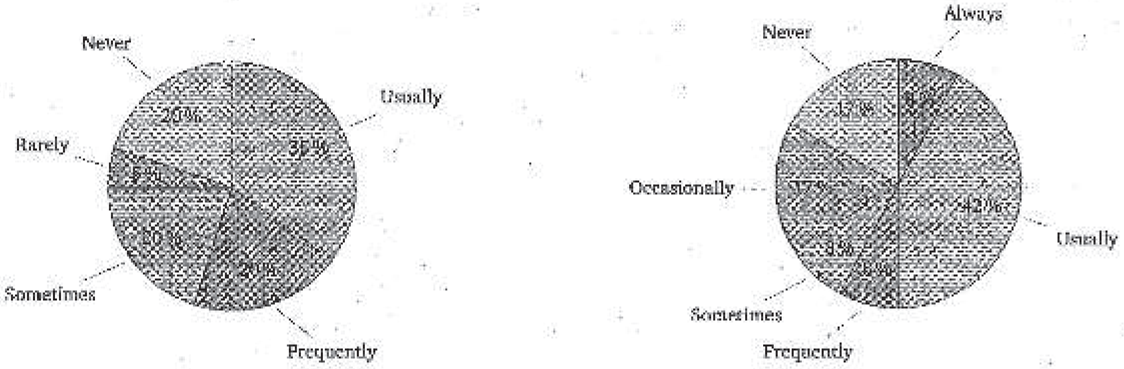
(d) Familiarity with motion (Phase2)

Figure B.9.: Familiarity with touch and motion gestures

B.3.1.1. General observations

In total, we have collected 1070 gestures in phase 1 (healthy group) split into 536 and 534 gestures for the two imposed restrictions levels (with/without hands & arms) respectively. In the second study phase (impaired participants), we have collected 637 gestures split into 320 and 317 gestures for the two imposed restrictions levels (with/without hands & arms) respectively.

In total, only very marginal number of experimental rounds were skipped by participants during the study with 1707 successfully executed referents out of 1728 referents. Skipping a referent occurred when the participant was not able to propose a gesture for a particular referent.



(a) Participants (Phase1)

(b) Participants (Phase2)

Figure B.10.: Familiarity with working in offices (current and previous)

B.3.1.2. Thinking time

We have investigated the thinking time required for each proposed gesture. We aimed to analyze differences between the two participant groups (i.e. healthy and impaired) and the two imposed restrictions levels (with and without hands & arms). The thinking time was measured by calculating the time after demonstrating the task until the start of the gesture execution.

The average thinking time for defining a gesture is 13.21 second. The average thinking times for the healthy and impaired participants were 14.02 and 11.82 second respectively. The thinking time between the two groups differed significantly (Mann–Whitney U = 297295, P = 0.002 two-tailed). These results suggest that the healthy group took longer thinking time than the impaired group.

Comparing the two imposed restrictions levels suggests a significant difference in the scores for thinking time (Mann–Whitney U = 301948, P = 0.000 two-tailed) with hands 14.41 second and without hands 11.99 second. The results suggest that the thinking time was shorter for the imposed restriction. A Spearman's rank-order correlation was run to determine the relationship between the thinking time for the two imposed restriction levels. The test revealed a weak positive correlation between the thinking times and the imposed restrictions levels, which was statistically significant (0.33, p = 0.000) when identical gestures were defined for the two levels. Similarly, a weak positive and statistically significant (rs = 0.327, p = 0.000) correlation was identified when different gestures were defined. The similarity between the two correlations indicates that the order of executing referents did not impact the thinking time.

Observation - **G1:**

Thinking time was slightly shorter in the case of natural or imposed impairments.

B.3.1.3. Gesture Types

We were interested to identify any preferences to use particular type of gestures between participants. Hence, we have labeled the participants' suggested gestures in terms of the following categories according to the gesture meaning:

- Metaphoric: Gestures in this category convey imagery of the abstract meaning, hence helping people to visualize difficult concepts that are entirely imaginative [28], e.g. finger pinches and hand waving.
- Real metaphoric: Gestures in this category are visual representation of real world physical or abstract meanings or ideas, e.g. the "Phone-to-ear" gesture by moving the hand to the ear to for accepting a phone call.
- Communicative (also called Performative): This category contains gestures that correspond to human non-verbal expression that indicate meanings, e.g. "Nod yes" or "Nod no" gestures to a accept or reject a certain action.
- Sonic: Gestures in this category are coupled or associated with generating sound, e.g. "Clap" and "Snap" gestures.
- Iconic: Gestures in this category are visual representations of referential meaning [4], e.g. rapid up and down hand movements may indicates the action of "Cutting" or "Chopping" gestures. Those gestures are often performed in conjunction with words to refer to concrete things and actions [28].
- Emblemic (also called Symbolic): Gestures in this category are considered highly conventional and 'lexicalized' [4]. Examples of such gestures include "Thumb up" gesture meaning "well done" or the "X" gesture meaning "rejection or refusal".
- Arbitrary: Gestures that were hard to interpret or classify into a category due to vague meaning.

Running the Pearson χ^2-test revealed statistical significant association between the participant's health and the selected gesture categories (X (6) = 29.05, p = 0.000). Nonetheless, the effect size (or strength of association) according to Cramer's V is 0.13 that indicates a weak effect. Figure B.11 (a) illustrates that both metaphoric and real metaphoric gestures were the most used types of gestures in our study. Metaphoric gestures were proposed the most with 54.32% and 52.34% for the impaired and healthy participants respectively. Although marginal, the figure shows that impaired relied on more real metaphoric gestures (26.22%) than healthy participants (20.75%). Communicative gestures were used more by the healthy (12.43%) than by impaired participants (5.97%).

Observation - G2:

Metaphoric and real metaphoric gestures are the most used types used by participants.

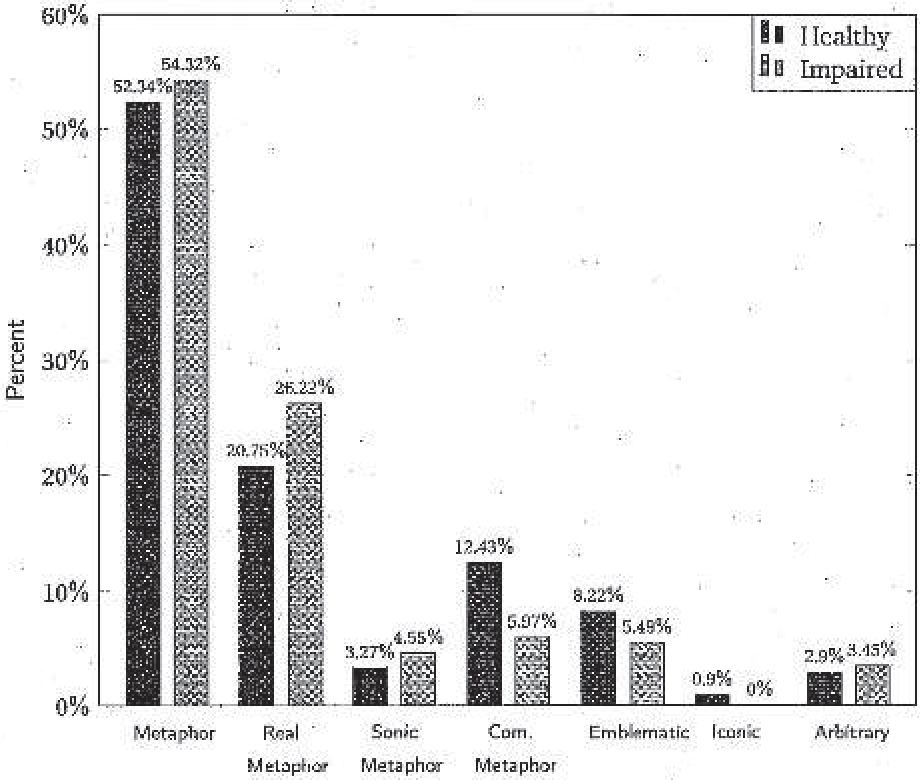
When comparing the two complexity levels in our study, the Pearson Chi-Square test revealed statistical significant association between using or not using hands for gestures X (6) = 171.65, p = 0.000. Nonetheless, the effect size (or strength of association) according to Cramer's V is 0.317 which indicates a medium effect.

Figure B.11(b) illustrates that the use of metaphoric gestures were used the most with 59% for the condition using hands and 47% for the condition without hands. The real metaphoric gestures came second (23%) almost equally for both conditions. The use of communicative metaphors increased to 18.68% for the condition without hands. Emblemic gestures were dropped approximately to 3.76% for the imposed restriction not to use hands or arms.

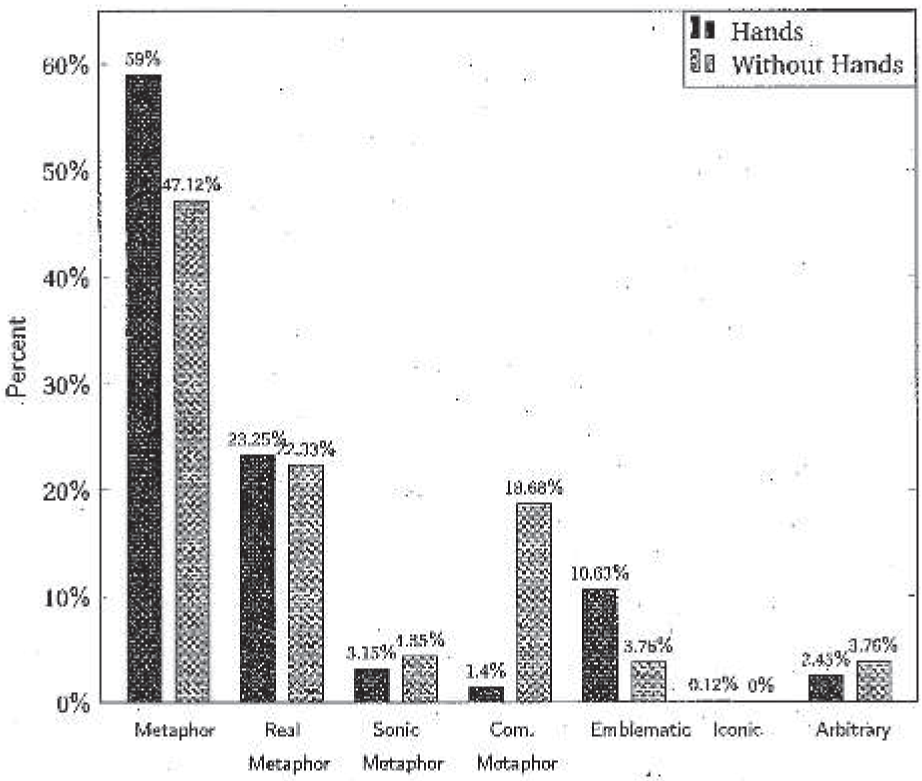
B.3.1.4. Gesture Set

In order to identify whether our participants agreed on a particular gesture set and the extend of agreement, we have analyzed the proposed gesture set for all referents in the study. In total 94 unique gestures were defined by our participants. Applying Likelihood-Ratio χ^2-test revealed statistical significant association between the health condition of the participant and selected gesture category (X (93) = 275.80, p = 0.000). With an effect size of 0.378, Cramer's V indicates medium effect. Figure B.12 illustrates the top 10 most occurred gestures during the study. A detailed view of the generated gestures is shown in Appendix V.

For each referent, we have plotted and analyzed the top selected gestures for the (a) healthy participants, (b) impaired participants, an over all comparison between the two groups, and an over all chart for the two complexity conditions. The corresponding charts for each referent can be found in Appendix VI. A summary of the most selected gestures for each referent for each of our test groups is illustrated in Table B.3. Marked (i.e., colored) gestures in the table present gestures selected by the majority of participants. The values below the gesture name indicates column by column the percentage portion of that gesture in regard of level and phase.

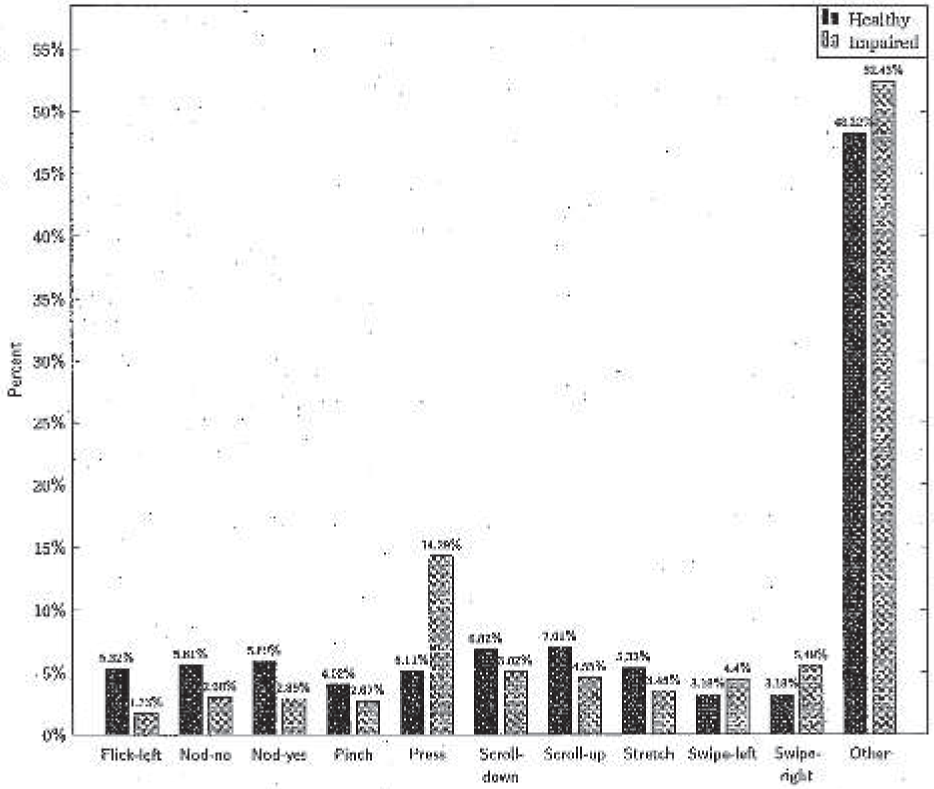


(a) Gesture meaning (according to health condition)

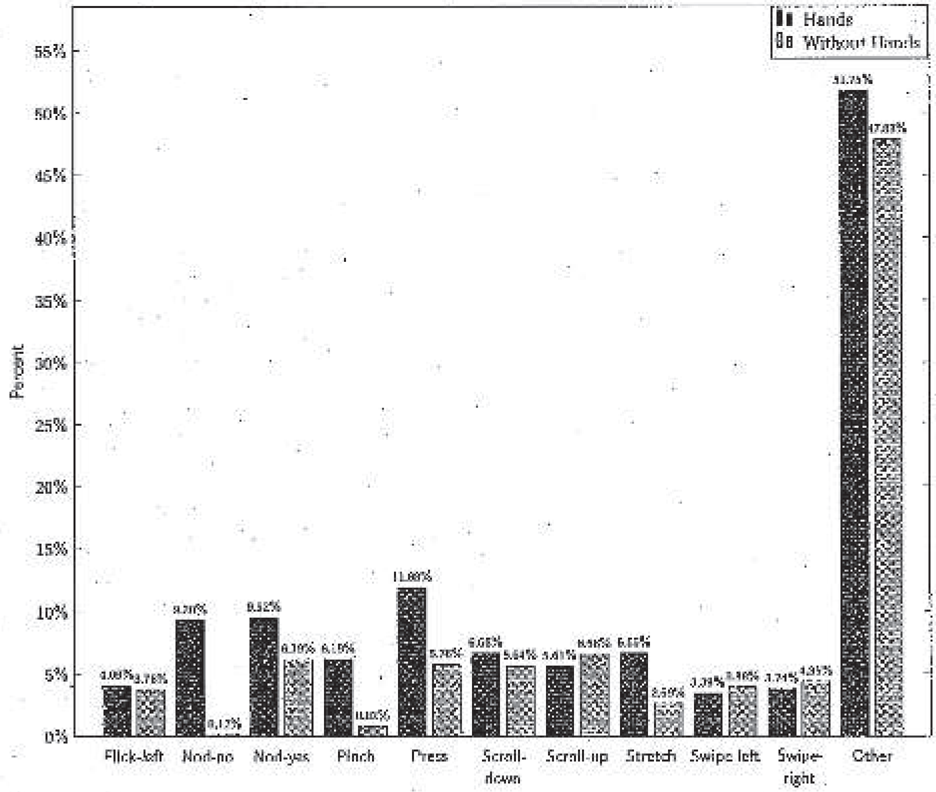


(b) Gesture meaning (according to imposed restriction levels)

Figure B.11.: Most occurred gesture meaning categories



(a) User-generated gestures according to the two groups (Healthy / Impaired)



(b) User-generated gestures according to the two complexity levels (With / Without Hands)

Figure B.12.: Most Selected User-generated Gestures (Gestures that occurred at least 3%)

Table B.3 clearly shows that out of 108 different cases (27 Referent x 4 Conditions) only 19 referents scored a strong or very strong agreement of a gesture for that referent, which presents merely 17.59%. This percentage clearly indicates that our experiment did not reveal a single gesture set with a majority agreement amongst participants. In fact, this supports our argument that a single unified gesture set cannot be defined due to the diversity of users (needs, capabilities, experiences and preferences).

Moreover, the suggested gestures revealed a low similarity score between the gestures created for the two imposed restriction conditions. In total, 8.22% of the gestures were similar by healthy participants (88 similar out of 1070 suggested gestures) and 7.37% of the gestures were similar by impaired participants (47 similar out of 637 suggested gestures).

Code	**Referent**	**Healthy With Hands**	**Impaired With Hands**	**Healthy Without Hands**	**Impaired Without Hands**
B1	Open Blinds	Scroll up (%70)	Scroll up (%33.33)	Scroll up (%50)	Scroll up (%41.67)
B2	Close Blinds	Scroll-down (%60)	Scroll-down (%41.67)	Scroll-down (%50)	Scroll-down (%41.67)
D1	Tabletop Delete Object	Draw-X (%20)	Press Pick-n-throw Wipe (%16.67)	Flick-left (%20)	Swipe-left Wipe (%8.33)
D2	Tabletop Accept Action	Thumb-up (%30)	Press (%50)	Nod-yes (%70)	Nod-yes (%53.85)
D3	Tabletop Reject Action	Draw-X (%23.81)	Flick-right (%18.18)	Nod-no (%75)	Nod-no (%53.85)
D4	Tabletop Change Background	Wipe (%16.67)	Swipe-right Wipe (%25)	Flick-left Swipe-right (%21.05)	Swipe-right Wipe (%16.67)
D6	Tabletop Zoom-in	Stretch (%80.95)	Stretch (%45.45)	Bend-fwd (%47.62)	Bend-fwd (%23.08)
D7	Tabletop Zoom-out	Pinch (%76.19)	Pinch (%50)	Bend-bwd (%42.86)	Bend-bwd (%36.36)
L1	Turn Light On	Press (%36.84)	Press (%41.67)	Nod-yes (%30)	Press Knock (%25)
L2	Turn Light Off	Press (%25)	Press (%41.67)	Press Nod-no (%36.32)	Press (%25)

Code	**Referent**	**Healthy With Hands**	**Impaired With Hands**	**Healthy Without Hands**	**Impaired Without Hands**
L3	Change Light Color	Flick-left (%30)	Press (%25)	Flick-left (%20)	Rotate-clock (%41.67)
L5	Increase Light Intensity	Scroll-up (%45)	Knop-rot-clk Scroll-up Stretch (%25)	Scroll-up (%60)	Scroll-up (%36.36)
L6	Decrease Light Intensity	Scroll-down (%40)	Scroll-down (%36.36)	Scroll-down (%55)	Pinch Scroll-down (%25)
P1	Turn Printer On	Press (%44.44)	Press (%58.33)	Press (%35)	Nod-yes (%25)
P2	Turn Printer Off	Point (%38.1)	Press (%66.67)	Press (%35)	Press (%25)
P5	Delete Printer Job	Draw-X Flick-away Swipe-left (%15)	Press (%54.55)	Flick-left Nod-no (%20)	Knock Nod-no Swipe-right (%16.67)
T1	Accept Phone Call	Phone2Ear (%40)	Phone2Ear (%54.55)	Nod-yes (%75)	Swipe-left (%25)
T2	Reject Phone Call	Flick-left (%30)	Phone-down (%27.27)	Nod-no (%75)	Nod-no Step-away (%18.18)
T3	Change Contact	Flick-left Scroll-down (%20)	Press (%33.33)	Swipe-left Swipe-right (%18.75)	Bend-fwd Flick-left Swipe-right (%16.67)
T5	Increase Volume	Scroll-up (%40)	Press (%45.45)	Scroll-up (%36.84)	Scroll-up (%25)
T6	Decrease Volume	Scroll-down (%40)	Press (%41.67)	Scroll-down (%36.84)	Scroll-down (%25)
W1	Wall Delete Object	Draw-X (%25)	Wipe (%25)	Kick (%15)	Swipe-left (%25)
W2	Wall Accept Action	Thumb-up (%42.11)	Draw-yes (%28.57)	Nod-yes (%80)	Nod-yes (%45.45)

Code	Referent	Healthy With Hands	Impaired With Hands	Healthy Without Hands	Impaired Without Hands
W3	Wall Reject Action	Thumb-down (%30)	Draw-X (%27.27)	Nod-no (%65)	Nod-no (%54.44)
W4	Wall Change Background	Flick-left (%30)	Swipe-right (%25)	Swipe-right (%21.05)	Swipe-right (%33.33)
W6	Wall Zoom-in	Stretch (%78.95)	Stretch (%53.85)	Step-close (%26.32)	Slide-bwd Step-close Stretch (%18.18)
W7	Wall Zoom-out	Pinch (%78.95)	Pinch (%41.67)	Step-away (%31.58)	Fold Step-away (%28.57)

Table B.3.: Most Selected User-generated Gestures for Referents (Green: Very strong agreement score, Blue: Strong agreement score)

Observation - G3:

The proposed gestures do not reveal general agreement about a united gesture set, instead personalized and customized gestures sets are defined.

According to [33], we've calculated the agreement rate $\mathcal{AR}(r)$ for each referent r mentioned within Table B.1 of each restriction level and phase. The agreement rate describes the agreement among all participants regarding the selected gesture for a referent. It is calculated as follows:

$$\mathcal{AR}(r) = \frac{|P|}{|P|-1} \sum_{P_i \subseteq P} \left(\frac{|P_i|}{|P|} \right)^2 - \frac{1}{|P|-1}$$

With $\mathcal{AR}(r) \in [0 \ldots 1]$ where $|P|$ describes the amount of all collected gestures for one referent r as well as $|P_i|$ the amount of each mentioned gesture contained within P.

$\mathcal{AR}(r)$ Interval	Interpretation
⩽ .100	*low* agreement
.100 — .300	*medium* agreement
.300 — .500	*high* agreement
> .500	*very high* agreement

Table B.4.: Interpretation of agreement rates, taken from [39]

As illustrated in Figure B.13, we've calculated the agreement rates for all phases and impairment levels. As a result, healthy participants agreed very highly on five and highly on one gesture (see Figure B.13(a)) while being allowed to use their hands. With imposed restrictions, they likewise agreed on five gestures very highly and high on three (see Figure B.13(b)). In contrast, the impaired participants did not come to a very high agreement. However, they highly agreed on three gestures each for being allowed to use hands (see Figure B.13(c)) and imposed restrictions (see Figure B.13(d)).

The resulting agreement rates were interpreted as displayed in Table B.4.

Observation - G4:

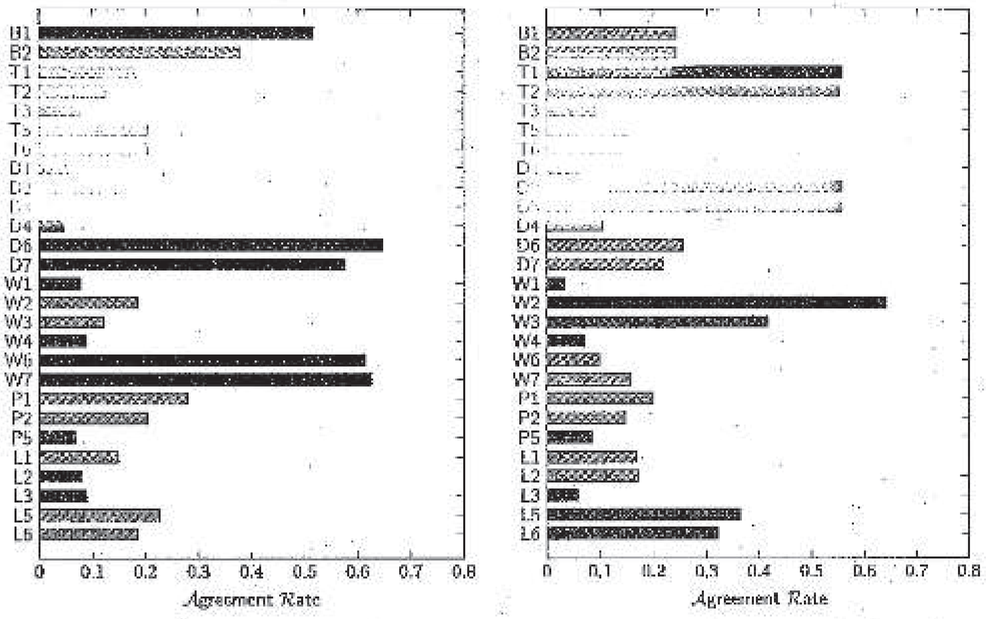
Impaired participants did not found a very high agreement on any referent, irrespective on whether they were allowed to use hands or not.

Observation - G5:

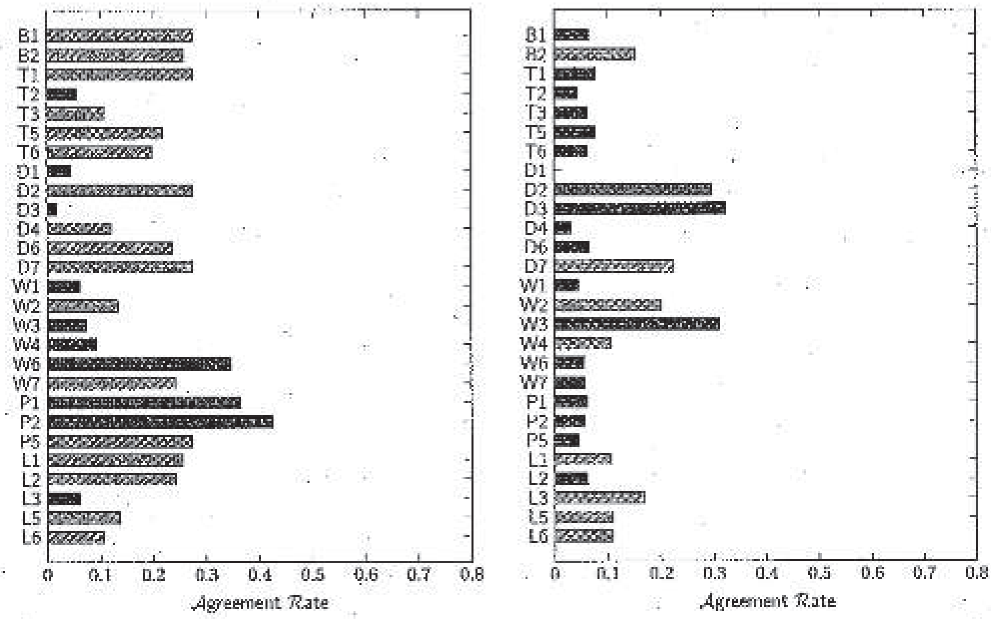
If healthy participants (very) highly agreed on a gesture for a referent, they also did for the complementary referent (e.g., accepting and rejecting).

B.3.1.5. Use of Body Parts

We have aimed to identify some key differences in using the body and its parts for interactions during our study. The experimenters recorded this information by directly observing the execution of gestures and by noting involved body parts while performing the gesture. The participants were then asked to explicitly confirm the used body parts for the gesture.



(a) Healthy with hands (b) Healthy without hands



(c) Impaired with hands (d) Impaired without hands

Figure B.13.: Agreement Rates

Kruskal Wallis test identified statistically significant differences among healthy and impaired participants (H (1) = 47.49, p = 0.000). Impaired participants employed more body parts during the execution of gestures (mean = 4.01) than healthy participants (mean = 3.34). Moreover, the test showed statistically significant differences for the level of imposed restrictions (H (1) = 247.35, p = 0.000). The average number of used (i.e., involved) body parts are 4.02 and 2.98 for "with hands" and "without hands" respectively, mainly because we have split the arm into three parts (arm, forearm and hand).

Figure B.14 illustrates the used body parts for executing the gestures defined by the participants. As expected, Figure B.14(b) shows that most healthy participants relied primarily on upper extremities, especially hands, forearms and arms for executing the gestures. Head and shoulders are well used as well. Likewise, impaired participants relied also on the upper extremities for executing the gestures, especially shoulders, hands, and forearms.

Figure B.14 (b) illustrates the used body parts when considering imposed restrictions. Clearly, our participants utilized mostly the movement of head and lower extremities, especially thighs, foots and calfs.

Observation - G6:

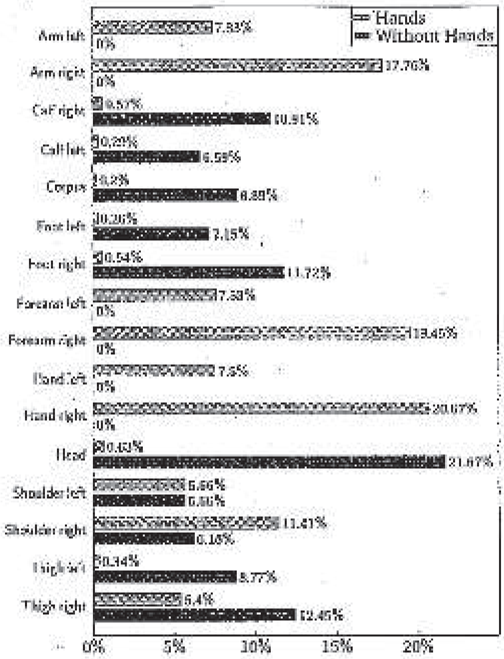
Impaired participants employed more body parts to execute the gestures than healthy participants.

Observation - G7:

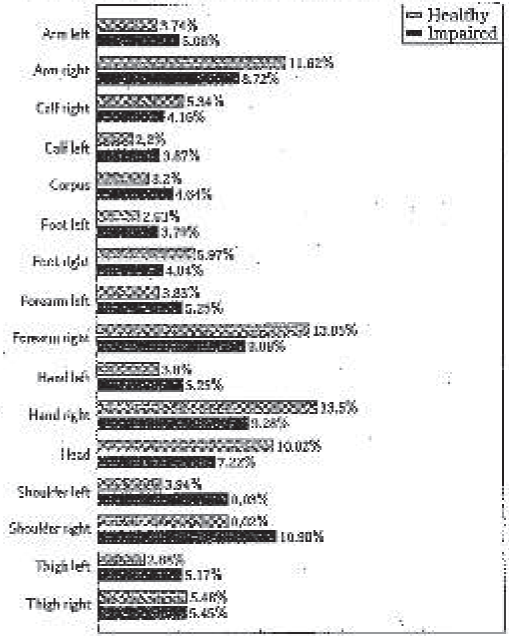
Participants relied primarily on upper extremities in the case of no imposed restrictions. Lower extremities were more engaged in the case of imposed restrictions.

Observation - G8:

Participants relied on different body parts to execute the gestures. Hence, no dominant preferred body part (i.e., body part set) was agreed on amongst the participants.



(a) Used body parts according to the two complexity levels (With / Without Hands)

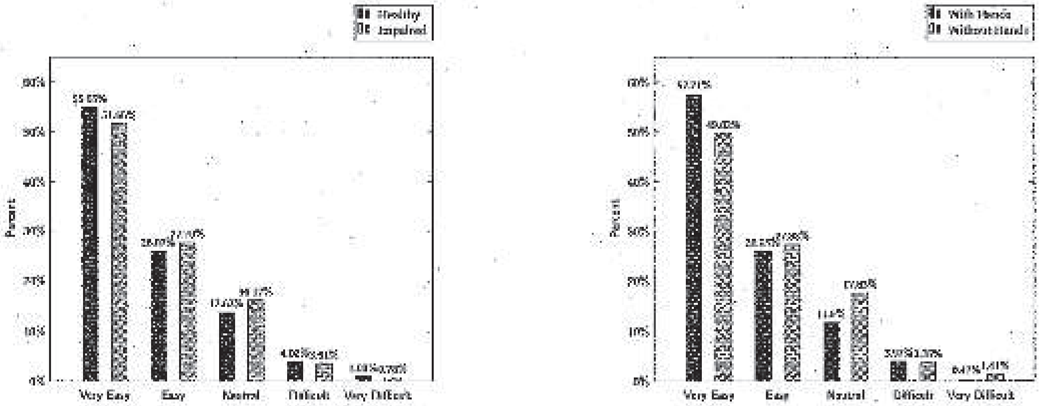


(b) Used body parts according to the two groups (Healthy / Impaired)

Figure B.14.: Used body parts

B.3.1.6. Gesture evaluation by users

After every executed referent, we have asked the participants to answer three Likert scale [75] questions. Firstly, we wanted to identify the cognitive load by asking the participants to answer the question "Was it easy to create the gesture?" from scale ("1" — very easy to "5" — very difficult). The Figure B.15(a) shows that the vast majority of participants found gestures easy to define regardless their health condition and imposed restrictions. Kruskal Wallis test identified no statistically significant differences among healthy and impaired participants. Nonetheless, the test revealed statistically significant differences (H (1) = 13.3, p = 0.000) amongst the imposed restrictions where gestures perceived slightly easier for "with hands" than "without hands". The mean ranks for the two levels were 1.63 and 1.80 respectively. The detailed scores can be seen in Figure B.15.



(a) Cognitive load (according to test groups)

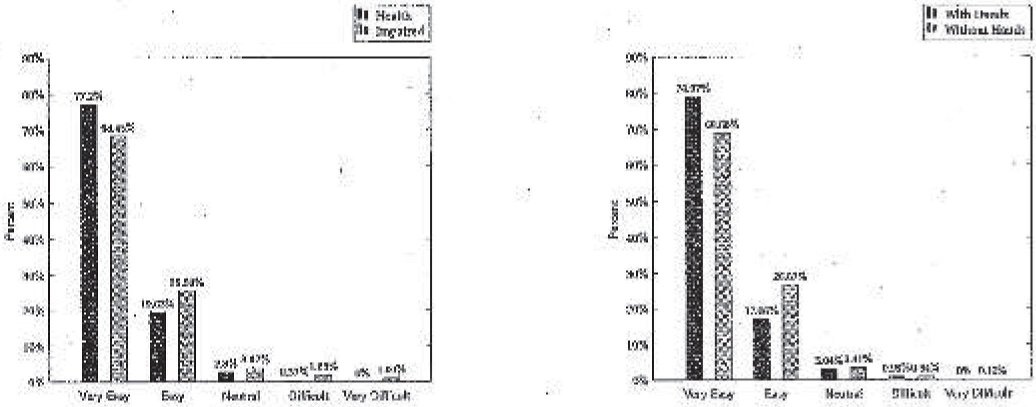
(b) Cognitive load (according to imposed restrictions)

Figure B.15.: Cognitive load needed for defining the gesture (Question: Was it easy to create this gesture?)

Observation - G9:

The majority participants found the gestures either very easy or easy to create. Moreover, gestures were perceived slightly easier when no restrictions applied.

We aimed also to identify the execution load by asking the participants to answer the question "Was it easy to execution the proposed gesture?" from scale ("1" — very easy to "5" — very difficult). The Figure B.16(a) shows that the vast majority of participants found gestures easy to execute regardless their health condition and imposed restrictions. Kruskal Wallis test identified statistically significant differences among healthy and impaired participants (H (1) = 17.12, p = 0.000). The mean ranks for the two groups were 1.26 and 1.4 respectively. Additionally, the test revealed statistically significant differences (H (1) = 21.05, p = 0.000) amongst the imposed restrictions where gestures perceived slightly easier for "with hands" than "without hands". The mean ranks for the two levels were 1.26 and 1.37 respectively.



(a) Execution load (according to test groups)

(b) Execution load (according to imposed restrictions)

Figure B.16.: Execution load needed for defining the gesture (Question: Was it easy to execution the proposed gesture?)

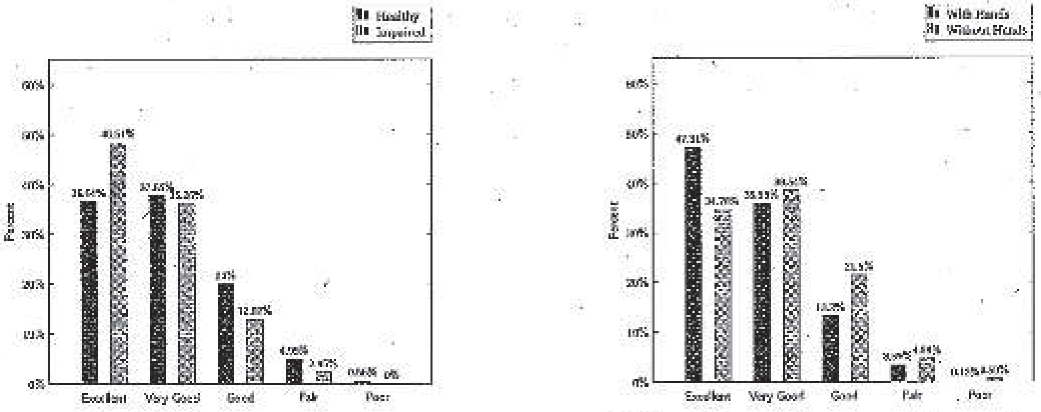
Observation - G10:

The vast majority of participants found the gestures either very easy or easy to execute. Moreover, gestures were perceived slightly easier for healthy participants and when no restrictions imposed.

We have asked the participants to rank the quality of their defined gesture for the given referent by asking the participants to answer the question "How good does the gesture fit the referent?" from scale ("1" — excellent to "5" — poor). The Figure B.17 shows that the vast majority of participants found their defined gestures fit the referents regardless their health condition and imposed restrictions. Kruskal Wallis test identified statistically significant differences among healthy and impaired participants (H (1) = 33.4, p = 0.000). The mean ranks for the two groups were 1.95 and 1.69 respectively. Additionally, the test revealed statistically significant differences (H (1) = 35.78, p = 0.000) amongst the imposed restrictions where gestures perceived slightly better fit to the referents for "with hands" than "without hands". The mean ranks for the two levels were 1.73 and 1.98 respectively.

Observation - G11:

The vast majority of participants believe that gestures well fit to the tasks. Furthermore, gestures were found better fit by impaired participants and when no receptions imposed.



(a) Matching quality (according to test groups)

(b) Matching quality (according to imposed restrictions)

Figure B.17.: Matching quality needed for defining the gesture (Question: How good does the gesture fit the referent?)

B.3.1.7. Semi-Structured Interview

In addition to the Guessability study, a semi-structured interview [26, p. 62ff.] was carried out. Each participant was asked to answer questions from three different categories, namely strategy, acceptance, and healthy working, in relation to the previously study phase. In order to deepen the discussion, a number of further questions for each category was asked to probe each participants opinion. In the following the key results for each category will be presented.

B.3.1.8. Strategy

Firstly, the participants were asked, if they used a certain strategy while bringing the gestures. As shown in Figure B.18, 26% of the healthy and 38% of the impaired participants applied everyday movements to the given tasks. Moreover, 19% healthy and 15% impaired participants attended for consistency among the gestures. Known touch-based gestures (from touch-based devices like smartphones, tablets, tabletop etc.) were adapted by 30% of the healthy and 8% of the impaired participants. This finding might correlate to the influence of previous experience with touch interfaces (80% healthy, 46% impaired, see Figure B.22).

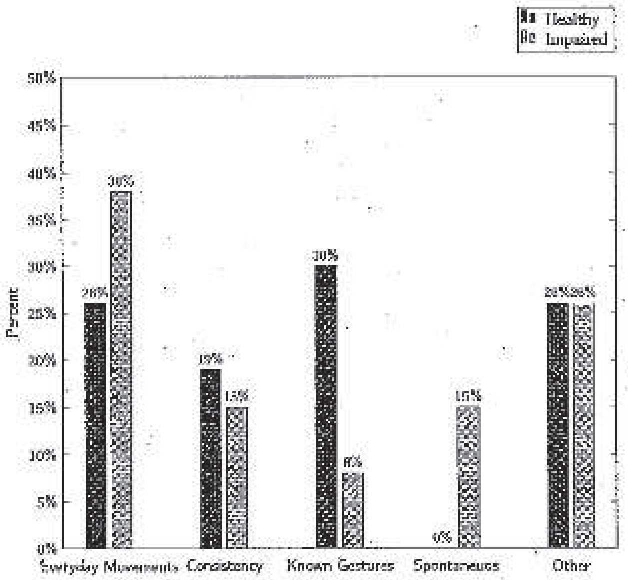


Figure B.18.: IQ 1 How did you choose/select your gestures? Did you have a particular strategy? (Phase 1 and 2)

Nearly each participant of both groups looked for simple gestures, quick and mapping of gestures (see Figure B.19 and Figure B.21). Novelty and innovation were considered of no importance as shown in Figure B.20. According to the participants opinion, 45% of the healthy and 54% of the impaired prefer to use customized gestures for controlling a system. Moreover, 30% healthy and 38% impaired participants prefer a hybrid (customise a given gesture set) to their own needs (see Figure B.23).

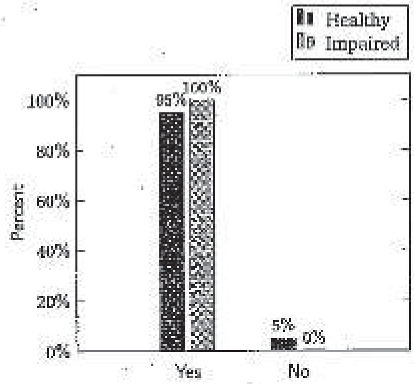


Figure B.19.: IQ1.1 Did you look for simplicity? (Phase 1 and 2)

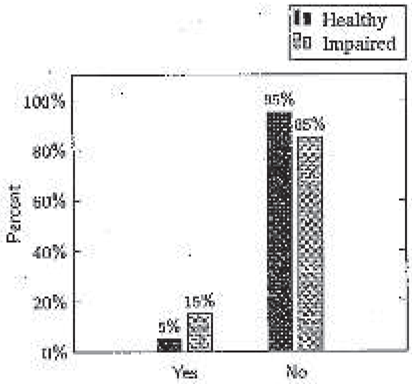


Figure B.20.: IQ.1.2 Did you look for innovation and novelty? (Phase 1 and 2)

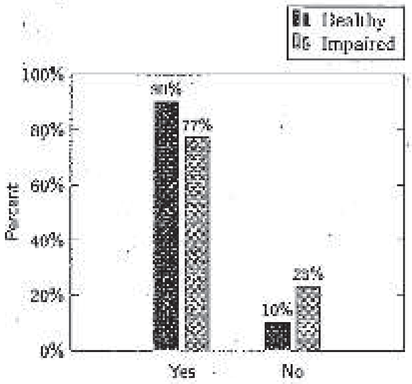


Figure B.21.: IQ 1.3 Did you look for quick and simple mapping? (Phase 1 and 2)

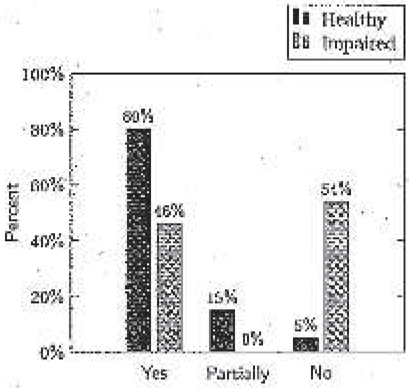


Figure B.22.: IQ 1.4 Were you influenced by your previous experience with touch interfaces? (Phase 1 and 2)

Observation - G12:

The vast majority of participants attend to simplicity, direct mapping, everyday movement, and consistency to define gestures. Variations still exist amongst the tested groups. While healthy participants relied on known gestures; impaired participants relied on spontaneous thinking.

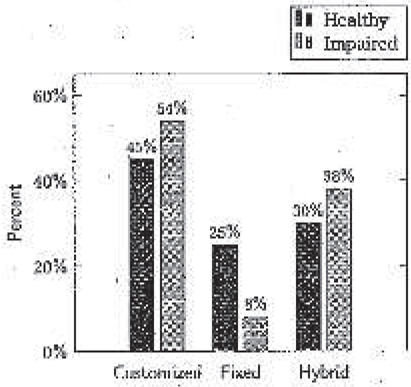


Figure B.23.: IQ 1.5 Do you like to customize gestures yourself or do you prefer fixed sets? (Phase 1 and 2)

Observation - G13:

The vast majority of the healthy participants were influenced by their previous experiences with multitouch gestures. In contrary, impaired participants were not influenced by multitouch gestures.

Observation - G14:

Participants did not consider innovation and novelty as a strategy to define gestures.

Observation - G15:

Participants prefer to use customized and hybrid gesture sets than fixed sets.

B.3.1.9. Acceptance

Secondly, the acceptance of using the full-body motion-gestures for controlling devices within the office was discussed. According to Figure B.24, 69% of the impaired are willing to engage their whole body for interaction, whereas in contrast 65% of the healthy participants wouldn't. This illustrates a high contrast between the two groups. Figure B.25

shows that 40% of the healthy and 23% of the impaired participants unconditionally accept the usage of full-body motion-gestures in the office. Moreover, the healthy (45%) and impaired (62%) participants indicate that motion gestures can be used for limited number of office activities. Only a small minority refuses the use of motion gestures in offices.

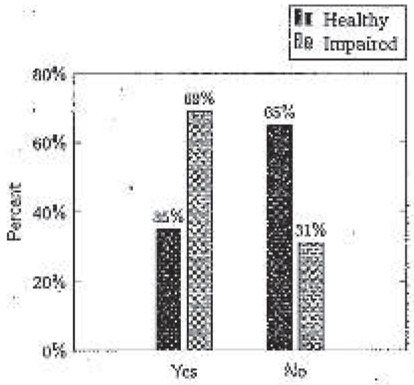


Figure B.24.: IQ2.1 Would you use your full body as an interaction medium with your smart office? (Phase 1 and 2)

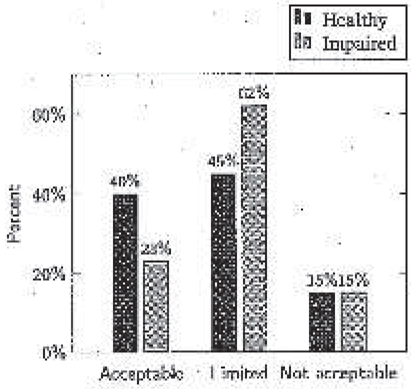


Figure B.25.: IQ 2 How acceptable is the idea of using full body motion gestures in office? (Phase 1 and 2)

Observation - G16:

The majority of impaired participants is willing to engage their full body in motion gestures, in contrast to healthy participants who with a majority refused to this engagement.

Observation - G17:

The majority of participants accept (also conditionally) accept the idea of using full body motion gestures in offices.

B.3.1.10. Healthy Working

Thirdly, the use of full body motion-based gestures for supporting healthier working conditions was subject of the interview. 85% impaired and 60% healthy participants saw potential in using whole body gestures for a healthier office and work style. On this basis, 85% impaired could imagine to use the office as a trainings center using full body motion gestures, contrasting to 75% healthy participants, who couldn't, as illustrated in Figure B.27.

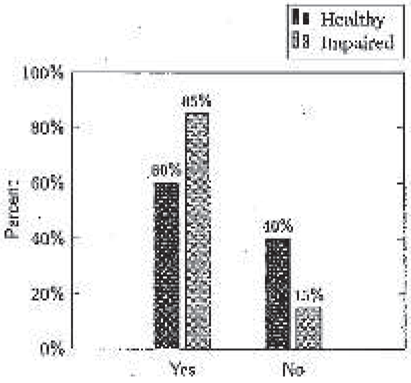


Figure B.26.: IQ 3 Do you see the potential for using whole body gestures for a healthier office and work style? (Phase 1 and 2)

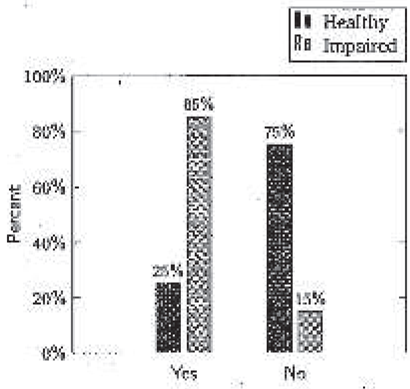


Figure B.27.: IQ3.1 Can you imagine using the office as a training center? (Phase 1 and 2)

Observation - G18:

The majority of healthy participants and vast majority of impaired participants acknowledge the potential of using whole body gestures for a healthier office and work style.

Observation - G19:

The vast majority of impaired participants could imagine the office as a trainings environment using full body motion gestures.

When asked the possible influences of utilizing full body gestures in office environments, the majority of healthy (80%) and impaired (69%) participants indicated that the productivity and concentration may be positively influenced as shown in Figure B.28.

Observation - G20:

The majority of participants believe that applying full body motion gestures may positively influence the productivity and concentration in office environments.

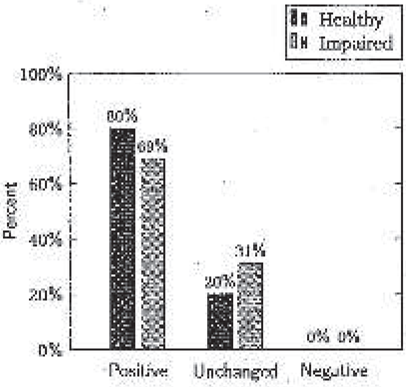


Figure B.28.: IQ 3.2 Do you think that this may influence your concentration and productivity? (Phase 1 and 2)

B.3.2. Feasibility Study — Phase 3

The 3rd phase of the study was carried out as a feasibility study based on the Wizard of Oz approach. In this part of the study, we have acquired 21 impaired participants undergoing rehabilitation process at the Bad Bramstedt hospital in Germany. Participants came from different professional backgrounds like handcraft, gastronomy, hairdresser and retail industry. The age of our participants ranged from 27 to 80 years with an average of 49.8 with 86% male and 14% female participants, as shown in Figure B.29.

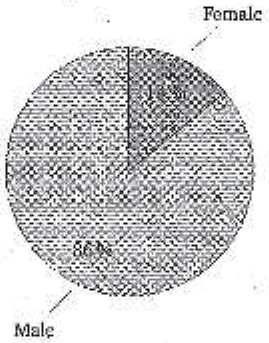
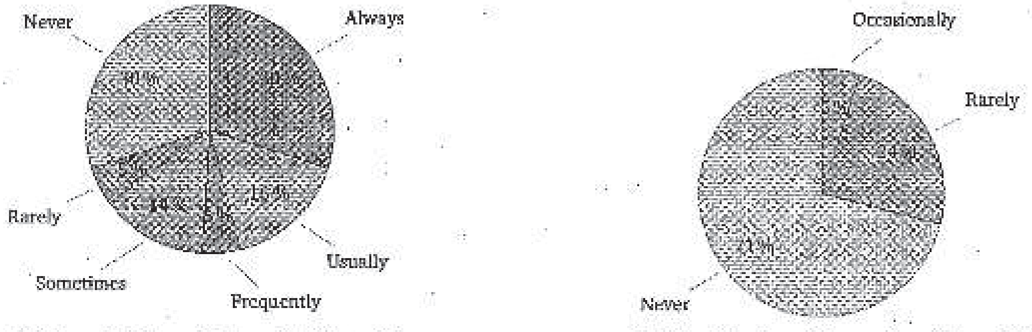


Figure B.29.: Participants (Phase3)

As illustrated in Figure B.30(a) 51% were familiar with touch interfaces. Furthermore, all of them had no or very less experience with motion based interfaces (see Figure B.30(b)). The minority of 34% among the participants were frequently working in an office or experienced office work, as shown in Figure B.31.



(a) Familiarity with touch (Phase3)

(b) Familiarity with motion (Phase3)

Figure B.30.: Familiarity with Touch and Motion Gestures

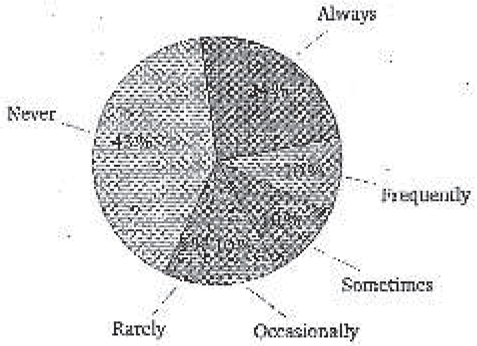
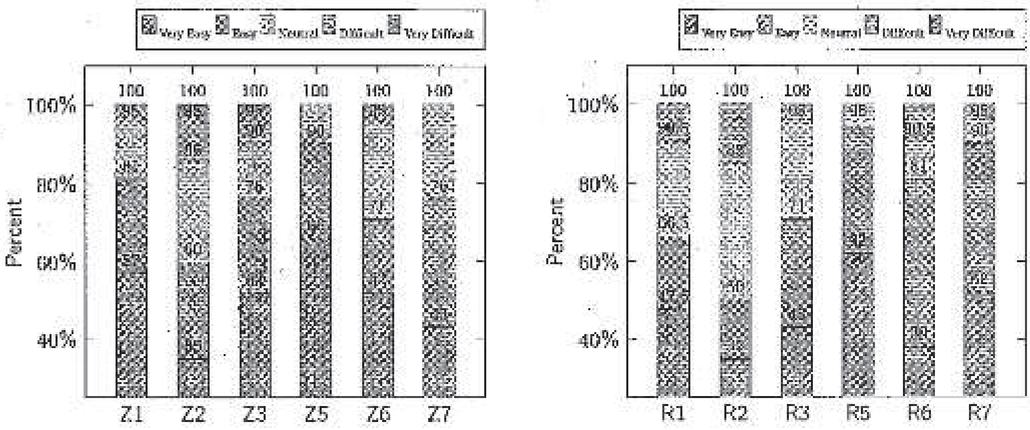


Figure B.31.: Familiarity with working in offices (current and previous) Phase 3

B.3.2.1. Ensembles evaluation

According to our experiment design, discussed in section B.1.3, the participants were asked to experience various Ensembles and asked to answer two Likert scale questions. A third question was added in case, that the participants were asked to define an Ensemble themselves. Figures B.32(a) and B.32(b) show, that most of the participants found gestures easy to execute. It is also visible, that single executed tasks (Z1 — Z3, R1 — R3) are found harder to execute than collaborative gestures (Z5 — Z7, R5 — R7). This is clearly resulted from the reduced physical effort required by the participants, as the collaborative Ensembles split load between two persons.



(a) Zoom gesture

(b) Rotate gesture

Figure B.32.: Execution load needed for performing the gesture (Question: Was it easy to execution the proposed gesture?)

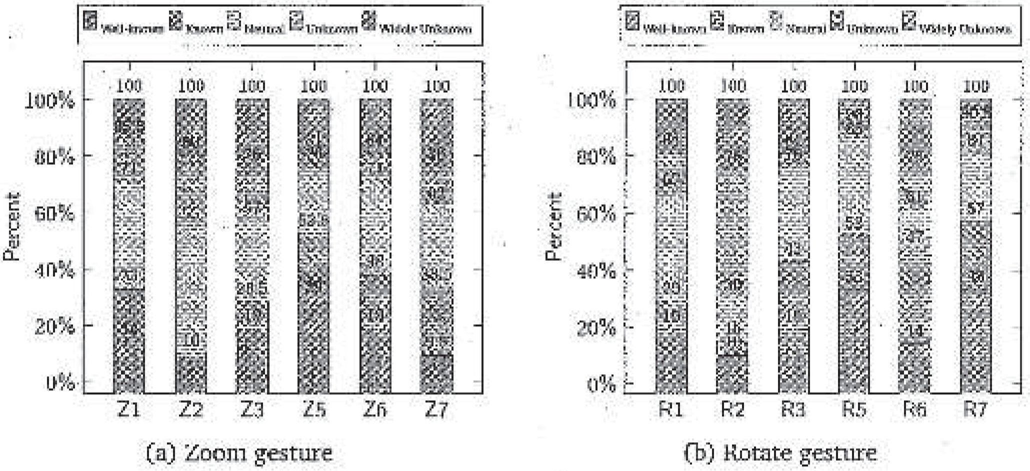
Observation - F1:

The majority of participants found most Ensembles easy to execute.

Observation - F2:

Collaborative Ensembles are perceived easier to execute than individually executed Ensembles.

In order to determine the level of familiarity of using Ensembles for controlling a system, we asked the participants to answer the question "Was the task common or known to you?" with Likert scale from ("1" — well-known to "5" — widely unknown). Figures B.33(a) and B.33(b) depict the results that single executed Ensembles (Z1, Z2, Z3, R1, R2, R3) were mostly unknown to participants, independent of the task. However, collaborative executed Ensembles are perceived more familiar to the participants, but this mainly results due to a learning effect.



(a) Zoom gesture

(b) Rotate gesture

Figure B.33.: Gesture familiarity (Question: Was the task common or known to you?)

All participant had the opportunity to define an Ensemble themselves at Z3, Z7, R3, R7. Therefore, we've asked each participant an additional question ("How easy was it to guess these configuration?") in order to find how cognitive demanding a customized Ensemble is. The answer should be in a Likert scale from "1" — very easy to "5" — very difficult. As illustrated in Figure B.34, the vast majority of the participants saw no difficulties to self-define/configure the Ensembles configurations.

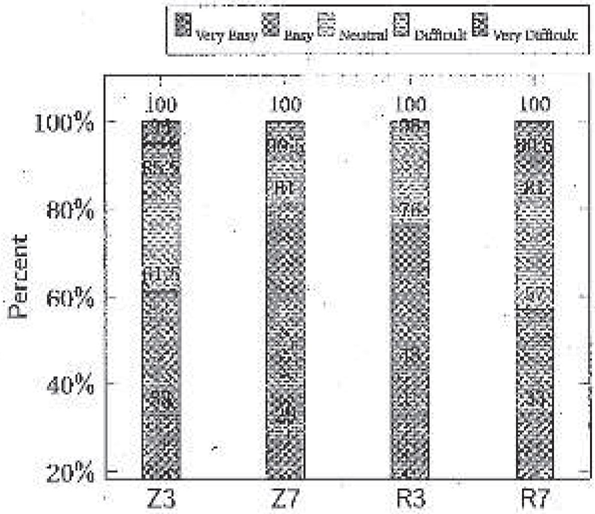


Figure B.34.: Cognitive load of defining an Ensemble (Question: How easy was it to define this configuration?)

Observation - F3:

Most of participants found it easy to self-define the Ensembles.

In terms of the used body parts, Appendix VIII (Figure I.29) illustrates that the arm and head were the most and the least used respectively. Moreover, the figure demonstrates that the participants dynamically engaged other body parts actively according to the task in hand.

Figure B.35 provides a close look at the participants' proposed Ensembles. The figure reveals that no dominant Ensemble was proposed by participants. Instead, various combinations and configurations were proposed. Ensembles proposed by participants the most in the individual user settings did not necessarily apply in the collaboration settings for the same referent. For example, touch and arm Ensembles were selected in 25% cases in the single mode for the zoom referent (Figure B.35(a)) and selected only 10% in the collaboration settings (Figure B.35(b)). Instead foot and arm Ensembles were selected by 24%.

Observation - F4:

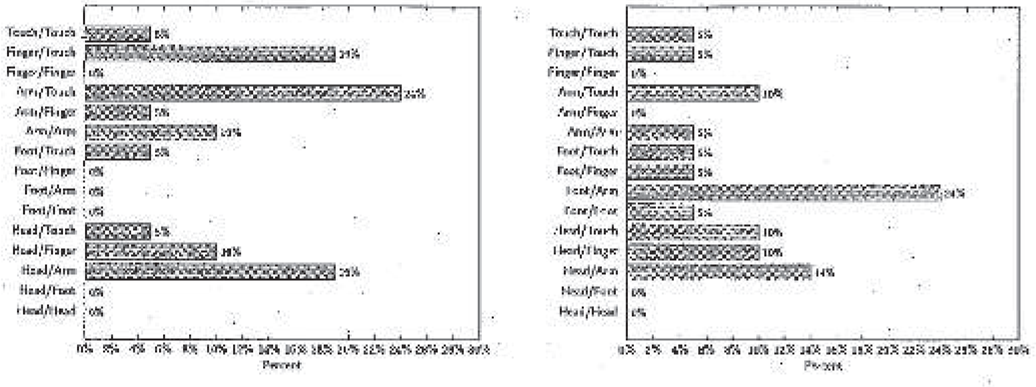
Self-defined Ensembles were mostly personalized, with no preferred or dominant Ensemble configurations.

B.3.2.2. Semi-structured interview

Similar to the previously study phases 1 and 2, we conducted a semi-structured interview in addition to the experience phase. Each participant was asked to answer questions from five different categories, namely strategy, acceptance, healthy working, opportunities, and accessing. In contrast to phase 1 and 2, the participants were able to experience the concept of Ensembles and were asked to give an assessment from their point of view. In the following the key results for each category will be presented.

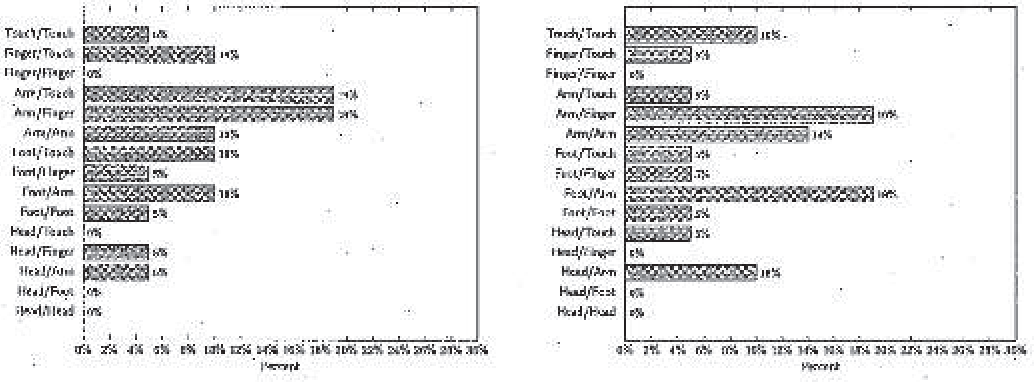
B.3.2.3. Strategy

First of all, the participants were asked, if a certain strategy should be applied to ideally create Ensembles. 33% mentioned, that the impairments of users should be considered, whereas 43% answered, that no particular strategy is needed, as shown in Figure B.36.



(a) Zoom single user

(b) Zooin collaborative



(c) Rotation single user

(d) Rotation collaborative

Figure B.35.: Chosen Ensembles

When asked explicitly about the most preferred Ensembles, arm in-air (27%) and finger in-air (27%) were the most preferred, followed by touch (24%). The involvement of head was preferred by 14% (see Figure B.37).

Observation - F5:

Despite their impairments, the participants preferred mostly Ensembles that employed the upper extremities.

The vast majority of participants require Ensembles to be simple (90%), novel (81%) and based on previous knowledge of touch interfaces (86%) as illustrated in Figures B.38, B.39 and B.40 respectively.

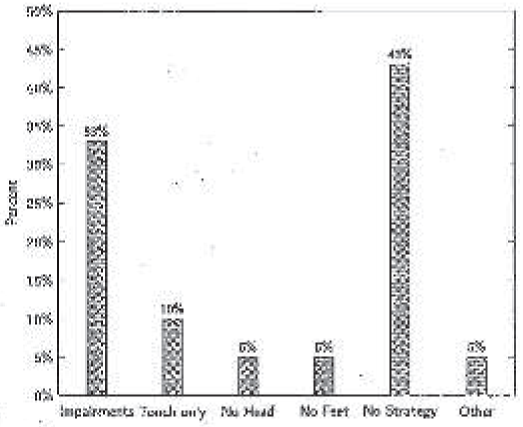


Figure B.36.: IQ1 P1 How Ensembles should be ideally created? / Should a particular strategy be applied? (Phase 3)

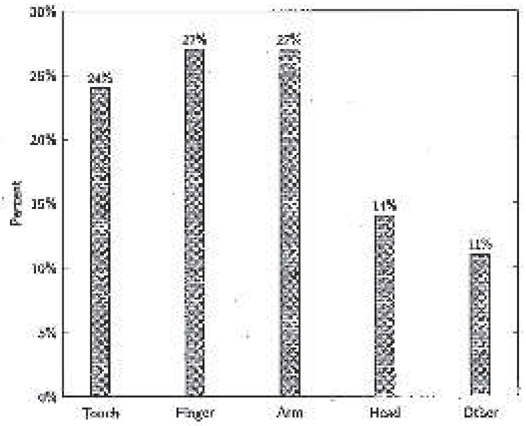


Figure B.37.: IQ1 P2 Which Ensemble-elements are the most preferred to you? (Phase 3)

Observation - F6:

The vast majority of participants require Ensembles to be simple, novel and related to previous known experiences.

Regarding customization, Figure B.41 illustrates that the bulk of the participants (67%) were in favor of customized Ensembles.

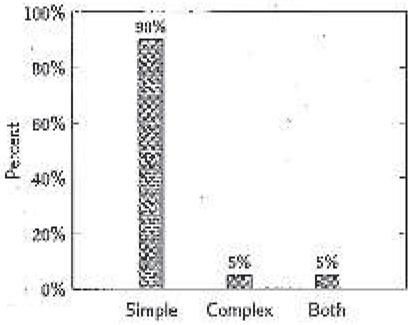


Figure B.38.: IQ1.1 Ensembles should be complex/simple? (Phase 3)

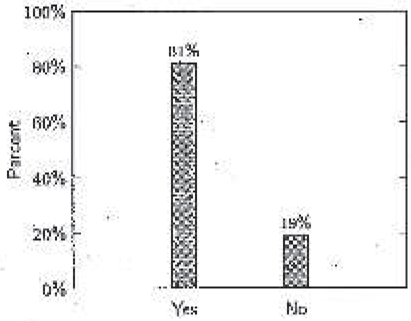


Figure B.39.: IQ1.2 Should Ensembles be innovate and novel? (Phase 3)

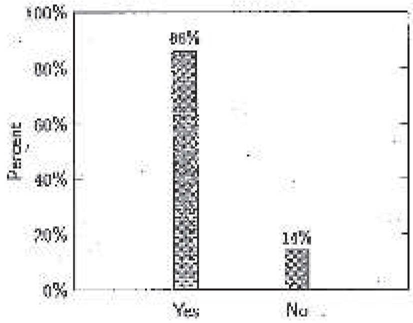


Figure B.40.: IQ1.3 Should Ensembles be influenced by the user's previous/known experiences (touch interfaces)? (Phase 3)

Observation - F7:

The bulk of the participants were in favor of customized Ensembles.

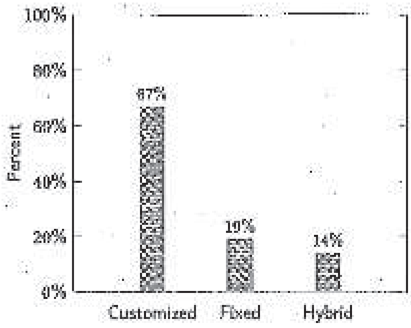


Figure B.41.: IQ1.4 Do you think you should be able to customizable your own set of Ensembles? (Phase 3)

According to the participants, the amount should not exceed 2 (46%) or 3 (31%) devices involved within an Ensemble (Figure B.42).

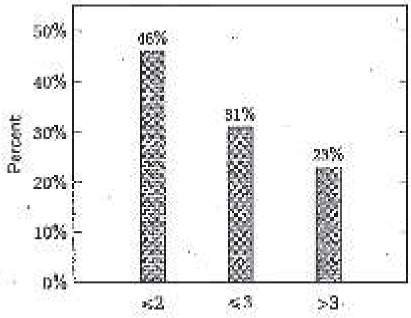


Figure B.42.: IQ1.5 How many devices would you choose? (Phase 3)

Observation - F8:

The majority of the participants believe that number of devices in Ensembles should be limited to 2 or 3 devices.

B.3.2.4. Acceptance

After experiencing the concept of Ensembles, 90% of the participants would accept these form of interaction without restriction of any kind in their daily office work, as illustrated in Figure B.43.

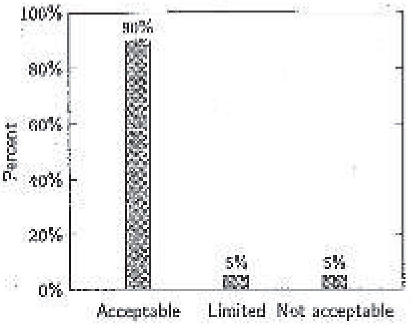


Figure B.43.: IQ 2 How acceptable is the idea of using full body motion gestures in office? (Phase 3)

Observation - F9:

The bulk of the participants accepted the use of Ensemble-enabled interactions without restriction of any kind in their daily office work.

More than half (57%) would use their full body as an interaction medium with their smart office as shown in Figure B.44. This result is close to the responses in the phase 2 of the study (see Observation G16).

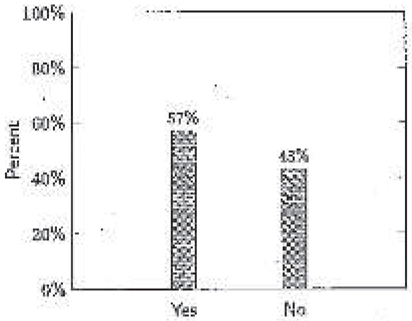


Figure B.44.: IQ2.1 Would you use your full body as an interaction medium with your smart office? (Phase 3)

Observation - F10:

The majority of impaired participants are willing to engage their full body in motion gestures.

Following the previous question related to novelty, we have asked the participants whether they actually did targeted their Ensembles to be novel and innovative, 57% of the participants did look for novelty and innovation in using Ensembles as illustrated in Figure B.45.

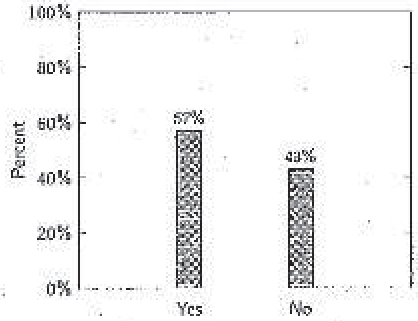


Figure B.45.: IQ2.2 Did you look for innovation and novelty? (Phase 3)

B.3.2.5. Healthy Working

When asked about the potential of using whole body for a healthier office and work style, 76% of the participants agreed that indeed whole body gestures and interaction can enabled a healthier office and work style as illustrated in Figure B.46. Moreover, 90% could imagine to use their office as a training center, especially for practicing rehabilitation exercises as shown in Figure B.47. Whereas 42% of the participants think, that using their full body as an interaction medium within office work would influence their concentration and productivity in a positive way, 48% of the participants believe, that these properties will remain unchanged (see Figure B.48).

Observation - F11:

The majority of participants agreed that indeed whole body gestures and interaction can enable a healthier office and work style.

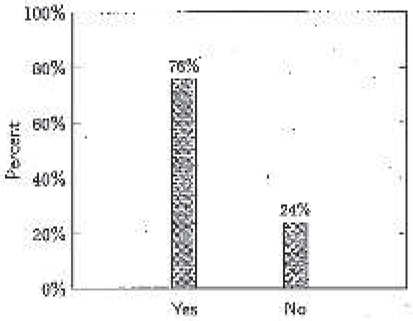


Figure B.46.: IQ 3 Do you see the potential for using whole body gestures for a healthier office and work style? (Phase 3)

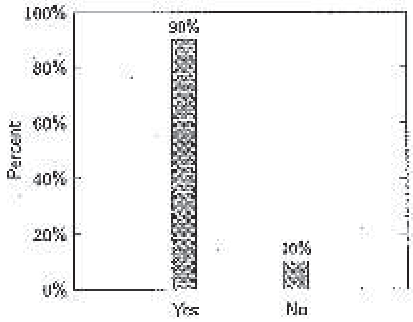


Figure B.47.: IQ 3.1 Can you imagine using the office as a training center? (Phase 3)

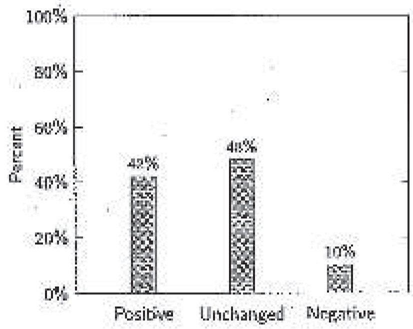


Figure B.48.: IQ3.2 Do you think that this may influence your concentration and productivity? (Phase 3)

Observation - F12:

The vast majority of participants could imagine to use their office as a training center, especially for practicing rehabilitation exercises.

Observation - F13:

The majority of participants believe that Ensembles may either positively or not influence their concentration and productivity.

B.3.2.6. Accessing

During the experiment, we have aimed to eliminate any cognitive factors that may influence the participants experience such as learning and memorization by selecting simple referents and demonstrating the Ensembles by one of the investigators. In this part of the interview, we have aimed at revealing any issues related to learning and memorizing Ensembles. When asked about learning new Ensembles, 71% pointed out that adequate instructions for using Ensembles of interaction techniques correctly are required (see Figure B.49). Under the prerequisite, that adequate guidance is provided, 67% of the participants have no reservations about learning theses interactions (see Figure B.50).

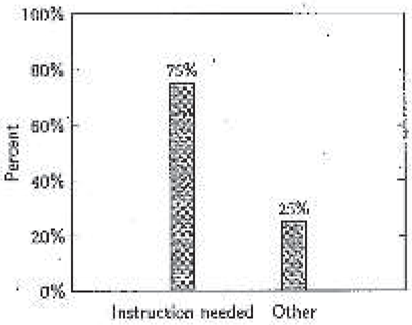


Figure B.49.: IQ 5 What do you think about learning and memorizing Ensembles? (Phase 3)

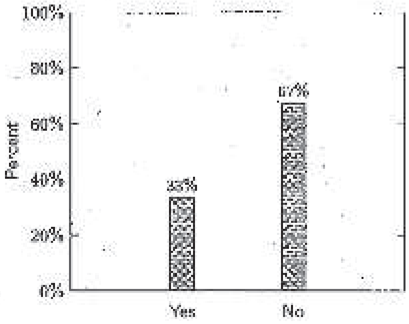


Figure B.50.: IQ 5.1 Do you think new Ensembles are difficult to learn? (Phase 3)

Observation - F14:

The majority of participants think that Ensembles are easy to learn. Nonetheless, they agree that adequate guidance is needed for learning new Ensembles.

Regarding the memorization of Ensembles, 57% of our participants think that memorizing Ensembles can not be hard, in contrary to 43% who believe that memorizing can be an issue as shown in Figure B.51.

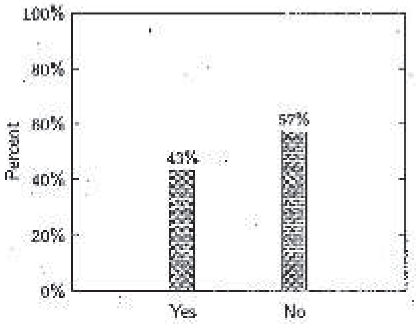


Figure B.51.: IQ 5.2 Do you think Ensembles are hard to remember and recall? (Phase 3)

Observation - F15:

The majority of participants think that Ensembles are easy to remember.

B.4. Discussion

B.4.1. The Myth of Gesture Sets

In the recent years, several elicitation studies for common user-defined gesture sets have been conducted as in [24,36,44]. This type of studies demonstrates the potential of an active user involvement in adjusting and customizing gestures for interactive systems and applications. While these studies presented interesting and novel user-defined gesture sets, we argue that many of the resulted gesture sets may be highly influenced by the study design itself (setup, referents and participants). For this reason, high attention to illuminating perceived affordances bias (e.g., animations and color-coding) in elicitation studies should be considered. In fact, we argue that user-defined gestures are very personal and mainly reflect the user's personal preferences, physical abilities and limitations, previous expertise, and expectations. Hence, standard user-defined gestures sets are very hard goals to achieve. Instead, the presence of user's individual differences is the normal fact to acknowledge. The results of our study support our argument as various observations (G3 and G4) clearly illustrate that no general agreement about a unified gesture set was found. Instead, defined user-defined gestures were highly personalized and customized.

The results (Observation G4) reveal that impaired participants had far more diverse and customized gesture sets than the healthy participants. Nevertheless, we could only report 10 gestures (18.5%) in the healthy participants group with very high agreement rates. When a high agreement rate was reported for a certain referent, it is most likely that the complementary referent is associated with a high agreement rate as well (G5). Moreover, high agreement rates were most reached for binary tasks (on/off, increase/decrease, etc.) that are of low complexity and did not require some specific knowledge of how a system works or might work. This is a clear indication that physical impairments (although closely similar in the impaired test group) force far more diversity in the suggested gestures. Hence, not a single very high agreement was observed for any of the gestures in the experimental rounds with impaired participants.

Our interview results show the importance of gesture customization to users. Observation G15 shows that users prefer to use custom and hybrid gestures far more than fixed gesture set. One participant (21 years old office administrator with limited range of movements in both fingers and arms) said that *"although it is more effort, I prefer to personalize and create gestures myself. They can be easier and learning is shorter."* On the other hand, another participant (68 years old retired) expected a level of customization based on active feedback but led by a specialist, she said that *"I would try the gestures and then provide feedback to the experts who should customize the gestures for me."* The variety and diversity of gestures resulted from the study and the absence of dominant preferred body part set (observation G8) directly indicate the involvement of personal needs and preferences in controlling an interactive system. Similar to defining gestures, the bulk of the participants were in favor of customized Ensembles as well (F7).

Finally, we argue that results of an elicitation study can only provide a snapshot of the current needs and found gesture sets might be valid only on short notice. Moreover, the physical needs, limitations and preferences can only be met with a dynamic, adaptive and customizable gesture sets.

B.4.2. Strategies for Defining Gestures and Ensembles

Different strategies were reported by the participants for defining gestures. While variations have been identified amongst healthy and impaired participants, most participants attended to simplicity, direct mapping, everyday movement, and consistency to define gestures (G12). It is conceivable, that a gesture feels more natural and easy to the users if they are easily able to built up a mental modal as well as memorize the chosen gesture for certain tasks and transfer those knowledge to other similar tasks. Therefore, the majority of participants did highly rely on metaphoric and real gestures (G2), which might be related to everyday movements and formerly learned gestures to reduce the cognitive load. In contrary to our expectations, observation G14 illustrates that innovation and novelty was not considered as a strategic factor for defining gestures by our participants. In our feasibility study, different strategies were identified for creating Ensembles including simplicity, novelty and previous known experiences (F6). Moreover, participants believe that the number of devices in Ensembles should be limited to 2 or 3 devices (F8).

Amongst the differences between the two participant groups, healthy participants relied on known gestures, while impaired participants relied on spontaneous thinking (observations G12 and G13). One possible explanation is that impaired participants have learned to compensate their limitations with spontaneous reacting for finding workarounds for everyday tasks they otherwise are not able to fulfill.

B.4.3. Bodily Experiences and Behaviors

The study reveals a number of observations regarding the differences and similarities in the bodily experience and behavior between healthy and impaired participants. As anticipated, when participants were free in choosing their body parts, they mostly relied primarily on upper extremities (G7). This is related to findings from section B.4.2, because most common mental models of interaction for office tasks and gesture control rely on interaction with that body parts. A direct transfer to gestures involving that body parts seems to be the least mentally demanding. Healthy participants strictly preferred using such body parts, because they might not see any need for involving other extremities, which probably feel less natural and direct than rehearsed interaction patterns and everyday movements with arms and hands. Despite their impairments, impaired participants preferred mostly Ensembles that employed the upper extremities (F5). Nonetheless lower extremities were more engaged when physical restrictions were imposed (G7).

In contrast to the healthy participants, impaired participants explicitly indicated that they are willing to be engaged in full body motion gestures (G16, F10, G6). Engaging the full body can compensate some of the physical limitations imposed by the impairment. These impairments often impact various parts of the participant's daily interaction with technology. One participant (54 years old physiotherapist with limited range of movements in the right hand due to job accident) mentioned that *"after working for an hour with the mouse, my right hand becomes cold and starts to ache. So browsing and editing our Christmas photo gallery is a real challenge."* Another participant (24 years old office administrator suffering from temporary disabilities in both arms and the right leg) said that "after the accident, it was not possible to do a lot of things including simple telephone calls. I would have preferred at that time to be given the chance to interact with other body parts." Some participants that indicated the joy of applying physical metaphors that are in real life not possible due to the impairments. For instance, during the interaction with the window blinds, a participant (51 years old journalist suffering from limited mobility in the left wrist and fingers due to metal implants) proposed the pull up/down gestures and immediately said that *"I know which gesture I will use because I cannot normally do it in practice. The physical rope is often very thin so I can only grasp it with the right hand but not in the left."* Only few participants have also indicated that they actually use accessibility interaction devices and that those devices are not ideal solutions to their problems. For example a 42 years old office administrator facing limited range of movements in the right arm said that *"the smaller the mouse is the worse it is. I have a relatively large compute mouse at home but it is still almost at the edge of me limits."* In fact, during the test rounds, impaired participants engaged on more body parts to execute the gestures than healthy participants (G6). This definitely contributes to a more diverse gesture set and a much more heterogenous behavior than the healthy group. Furthermore, a diverse engagement of the body and its movements can be seen as no dominant preferred body part (i.e., body part set) was identified amongst (G8), which also relates to the discussion in section B.4.1.

B.4.4. Customization and Acceptance

Generally, all impaired and healthy participants were successfully engaged in the guessability study, which can strongly indicate that whole body gestures are accessible and possible for all users and that they have the potential to reduce physical barriers. The results show that the cognitive load for self-defining gestures was mostly rated easy or very easy by the participants, even when physical restrictions were applied (G9, G10). Given the nature of the guessability study, all participants had the opportunity to see the systems' reaction before creating a gesture. Hence, they first were able to built up a mental model of how the system works and only then select a matching gesture, which supports the whole thinking process.

Additionally, most participants of both groups believe that their defined gestures well fit the tested referents (G11). This may be caused by the reduced cognitive demand due to a partially existing mental model. The reported scores decrease a bit when restrictions were imposed. A conceivable assertion might be the increased physical demand as well as the need for rethinking the preceding gesture selection. The majority of impaired participants explicitly indicated that they are willing to engage their full body in motion gestures (F10), which indicates a positive attitude towards the acceptance of Ensembles.

Although the office scenarios included in the study were explicitly introduced to the participants as home office scenarios, many participants have indicated in the interviews that the acceptability of full-body gestures depends greatly on the social setup. Various participants stressed that these forms of interactions can only be accepted in private. When asked about the acceptance of using full-body gestures in offices, one participant (51 years old journalist suffering from limited mobility in the left wrist and fingers due to metal implants) said *"it depends whether I work in the same office with collages. I find it very good if it is not in public. In public it could be very annoying and very bizarre."* Another participant (42 years old office administrator facing limited range of movements in the right arm) said that *"I would never use full body movements in a public office, but in private it's ok."*

In two cases during the study, participants have faced interaction problems due to wrong mental models that mainly relate to WIMP interaction style. A participant (21 years old office administrator with limited range of movements of fingers and arms due to an injury) said during the think-aloud protocol that *"I really imagine a virtual mouse with buttons and I use this mouse virtually as I would with a pc"*. In the imposed restrictions rounds of the study, he struggled to engage other body parts instead by saying that *"you almost cannot do anything in an office without hands, I think i need to think a bit more!"* Another participant (58 years old fireman) argued that *"this system is not acceptable, I would use mouse and keyboard."* Moreover, some participants have indicated a strong relation between interaction physical space (where the interaction takes place) and the body parts. For example, one participant (34 years old office assistant with limited thump movements in both hands) said during the interaction with the table that *"with the legs it is stupid, because the interactions happen on the table."*

B.4.5. Fullbody Gestures for a Healthier Office

Part of our investigation was aimed to investigate the acceptance to utilize and engage the full body for interaction purposes as part of a healthier working style in offices. Our hypothesis is that Ensembles in office environments offer a number of potential advantages, namely better efficiency and optimized ergonomics by attending to personalized ambient interactive systems and anthropometric user abilities and limitations. Typical office processes may also be part of health and rehabilitation training. In the long term, Ensembles supported by adequate feedback technologies and techniques aid to avoid bad physical behaviors and repetitive processes.

The conducted interviews reveal that using full body motion gestures and Interaction Ensembles in offices is generally accepted (G17, F9). Likewise, the majority of participants acknowledge the potential of using whole body gestures for a healthier office and work style (G18, F11). Additionally, the vast majority of impaired participants could imagine the office as a trainings environment using full body motion gestures and Interaction Ensembles, especially for practicing rehabilitation exercises (G19, F12). This is also supported by strongly indicating that such scansions may positively influence the productivity and concentration in office environments (G20, F13).

B.4.6. Acceptance of Ensembles

In general, the Interaction Ensembles concept and experience were positively perceived by participants. The majority of participants perceived most Ensembles easy to execute (F1) and (self-) define (F3). One participant (52 years old electrician) mentioned that *"to minimize the memorizing load, I would use the easiest Ensemble."* Although not common for the participants, collaborative Ensembles are perceived easier to execute than individually executed Ensembles (F2), which may be caused by the fact, that the participants only had to execute half of the whole movement. Some participants expressed that the Ensemble should work perfectly to be accepted. For instance one participant (32 years old draftsman) mentioned that *"It is acceptable for office work, but it has to work perfectly to stay productive."*. On the other hand, few participants did not accept the concept due to various reasons. One participant (44 years old hairdresser suffering from a complete disability in left arm) said that *"I don't think I need this . . . I would not remember such configurations"*.

Clearly, we have identified that self-define Ensembles were mostly personalized, with no preferred or dominant Ensemble configurations (F4). This clearly matches arguments and observations discussed in section B.4.1.

Regarding the cognitive demand of self-created Ensemble, the majority of participants think that Ensembles are easy to learn (F14) and remember (F15). Nonetheless, they agree that adequate guidance is needed for learning new Ensembles (F14). Participant (45 years old nurse) mentioned that *"It is not necessary difficult, but training is needed."*

Chapter C CONCLUDING PART

C.1. Summary

Natural User Interfaces have found their way widely in commodity and household devices, not only to facilitate new interaction functionalities but also to provide new engaging experiences to the user. Such interaction paradigms highly utilize the users' cognitive and physical abilities. For various user groups suffering form impairments, especially limited mobility and stability of joints or limited control of voluntary movements, these interfaces can contribute to overcome some of their physical limitations. Likewise, they may cause a physical ability gap and increase the interaction challenges. In this project, we conducted a three-fold study consisting from a guessability study with 20 healthy participants, a guessability study with 13 impaired participants and a Wizard of Oz feasibility study with 21 impaired participants. The study was aimed to observe personal adaptation strategies (body engagement, custom gestures, etc.) to overcome physical impairments when interacting with gesture based interactive tasks, examine the potential for using full-body motion gestures for healthier and more accessible work places, and to evaluate feasibility of interaction Ensembles as an approach to overcome physical impairments for interactivity purposes.

Our study reveals that there is a strong tendency towards customized and hybrid motion gestures instead of common unified gesture sets for both healthy and impaired groups. In fact, participants relied on different body parts to execute the gestures with no dominant preferred body part (i.e., body part set) being identified. Nonetheless, the results reveal that impaired participants had far more diverse and customized gesture sets than the healthy participants. This is a strong indication that physical limitations pose more requirements towards personalization and custom gestures. Moreover, high agreement rates were most reached for binary tasks (on/off, increase/decrease etc.) that are of low complexity and did not require some specific knowledge of how a system works or might work. The interview results show the importance of gesture customization, as most users explicitly indicated that they are in favor of using custom and hybrid gestures far more than fixed gesture set. Similar to defining gestures, the bulk of the participants were in favor of customized Ensembles as well which directly indicates the involvement of personal needs and preferences in controlling an interactive system.

We have identified that most participants attended to different strategies to define motion gestures. While variations have been identified amongst healthy and impaired participants, most participants attended to metaphoric, real gestures, simplicity, direct mapping, everyday movement, and consistency to define gestures. Amongst the differences between the two participant groups, healthy participants relied on known gestures (previous experiences with legacy devices such as multitouch gestures) and impaired participants relied on spontaneous thinking. In contrary to our expectations, innovation and novelty were not considered important strategies to define gestures. Various strategies were identified to define Ensembles, namely simplicity, known experiences, and limited number of interaction devices (2 — 3 devices). Additionally, preferred Ensembles employ the upper extremities.

Generally, all participants were successfully engaged in the guessability study, which can strongly indicate that whole body gestures are accessible and possible for all users and that they have the potential to reduce physical barriers. The majority of the participants had no difficulties to create and execute the gestures. As expected, gestures were perceived slightly easier for healthy participants and when no restrictions imposed. Additionally, the vast majority of participants managed to successfully execute the tasks and believed that their custom gestures well fit to the tasks. The results show that the cognitive load for self-defining gestures was mostly rated easy of very easy by the participants, even when physical restrictions applied. The study results reveal clearly that majority of impaired participants are willing to engage their full body in motion gestures, in contrast to healthy participants who with a majority refused to this engagement.

The majority of healthy participants and vast majority of impaired participants acknowledge the potential of using whole body gestures for a healthier office and work style. This indicates a general acceptance to utilize and engage the full body for interaction purposes as part of a healthier working style in offices. The results support our hypothesis that Ensembles in office environments offer a number of potential advantages, namely better efficiency and optimized ergonomics by attending to personalized ambient interactive systems and anthropometric user abilities and limitations. Typical office process may also be part of health and rehabilitation training. In the long term, Ensembles supported by adequate feedback technologies and techniques aid to avoid bad physical behaviors and repetitive processes. The majority of participants believed that applying full body motion gestures may positively influence the productivity and concentration in office environments.

In general, the Interaction Ensembles concept and experience were positively perceived by participants. The majority of participants perceived most Ensembles easy to execute and (self-) define. Ensembles with less physical demands were perceived easier to execute. For example, although not common for the participants, collaborative Ensembles are perceived easier to execute than individually executed Ensembles, which may be caused by the fact that the participants only had to execute half of the whole movement. Some participants expressed that the ensemble should work perfectly to be accepted. On the other hand, few participants did not accept the concept due to various reasons (possible cognitive load to remember complex configurations). Nonetheless, the bulk of the participants accepted the use of ensemble-enabled interactions without restriction of any kind in their daily office work. Moreover, the majority of participants agreed that whole body motion gestures and interaction Ensembles can enable a healthier office and work style. Additionally, the vast majority of participants could imagine to use their office as a training center, especially for practicing rehabilitation exercises and the majority believed that Ensembles may either positively or not influence their concentration and productivity.

The bulk of the participants were explicitly in favor of customized Ensembles. During the study, self-defined Ensembles were mostly personalized and no preferred or dominant ensemble configuration, which indicates again the general tendency towards customization. Regarding the cognitive demand of self-created ensemble, the majority of participants think that Ensembles are easy to learn and remember. Nonetheless, they agree that adequate guidance is needed for learning new Ensembles.

We consider this novel study as a starting point for identifying the feasibility and acceptance of using full-body motion gestures and Ensembles for a healthier work space and work style. The results discussed in this report clearly demonstrate a great potential and high acceptability of the interaction ensemble approach.

C.2. Practical relevance of the results

We believe that the results of this study show the potential of using whole body gestures for a healthier office and work style and blurs the barriers between work and rehabilitation exercises. The results clearly demonstrate the possibility and importance of changing typical office process to be part of health and rehabilitation training. This requires not only the users' readiness be actively bodily engaged, but also employers' readiness to adapt and integrate new models of office work habits in workplaces.

The results of this study also demonstrate the impact of anthropometric bias in full-body motion gesture elicitation studies. While most elicitation studies are focused on healthy participants, our study reveals the importance of involving physically impaired participants. While different elicitation studies' bias factors, such as legacy bias, can be controlled, the physical anthropometric bias can be hardly controlled and is more prominent within user participants challenged with physical impairments. This was also reflected on the participants' willingness to engage with full-body motion gestures. We believe that full-body motion elicitation studies may benefit from the following recommendations: bias counter acting techniques must be considered and applied very carefully as they introduce their own bias that may contradict with the users' personal strategies; while elicitation studies are considered to follow a bottom-up approach, there is a need for a new hybrid approach that blurs the gap to the Top-down approach and satisfies the users' needs for personalized and hybrid gesture sets; elicitation studies should attend more to situatedness and should involve new groups of participants such as impaired users; and finally, the scope of the study results should not only be focused on gesture agreement rates but also on other measures, some of which have been covered in this paper such as users' engagement, user's strategy, gesture types, body coverage, ease of execution and task appropriateness.

C.3. Knowledge Transfer

This study demonstrates the importance of developing new methods for user-defined gesture sets that closely consider the anthropometric variations especially related to physical impairments. This requires a close collaboration between interactive system designers and rehabilitation specialists in oder to define new Top-Down models and to assist the accessibility of existing available user-defined interaction models and modalities.

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