Chair for Computer Science 10 (Media Computing and Human-Computer Interaction)

RWTH AACHEN UNIVERSITY

Investigating Peripheral Feedback for Sitting Posture Guidance

Master's Thesis
submitted to the
Media Computing Group
Prof. Dr. Jan Borchers
Computer Science Department
RWTH Aachen University

by
Julia Reim

Thesis advisor:
Prof. Dr. Jan Borchers

Second examiner:
Priv.-Doz. Dr. Jörg Eschweiler

Registration date: 18.10.2022
Submission date: 18.04.2023

Eidesstattliche Versicherung
Statutory Declaration in Lieu of an Oath

Reim, Julia
Name, Vorname/Last Name, First Name

354921
Matrikelnummer (freiwillige Angabe)
Matriculation No. (optional)

Ich versichere hiermit an Eides Statt, dass ich die vorliegende ~~Arbeit/Bachelorarbeit~~/ Masterarbeit* mit dem Titel
I hereby declare in lieu of an oath that I have completed the present paper/Bachelor thesis/Master thesis* entitled

Investigating Peripheral Feedback for Sitting Posture Guidance

selbstständig und ohne unzulässige fremde Hilfe (insbes. akademisches Ghostwriting) erbracht habe. Ich habe keine anderen als die angegebenen Quellen und Hilfsmittel benutzt. Für den Fall, dass die Arbeit zusätzlich auf einem Datenträger eingereicht wird, erkläre ich, dass die schriftliche und die elektronische Form vollständig übereinstimmen. Die Arbeit hat in gleicher oder ähnlicher Form noch keiner Prüfungsbehörde vorgelegen.
independently and without illegitimate assistance from third parties (such as academic ghostwriters). I have used no other than the specified sources and aids. In case that the thesis is additionally submitted in an electronic format, I declare that the written and electronic versions are fully identical. The thesis has not been submitted to any examination body in this, or similar, form.

Aachen, 18.04.2023
Ort, Datum/City, Date

Unterschrift/Signature

*Nichtzutreffendes bitte streichen
*Please delete as appropriate

Belehrung:
Official Notification:

§ 156 StGB: Falsche Versicherung an Eides Statt
Wer vor einer zur Abnahme einer Versicherung an Eides Statt zuständigen Behörde eine solche Versicherung falsch abgibt oder unter Berufung auf eine solche Versicherung falsch aussagt, wird mit Freiheitsstrafe bis zu drei Jahren oder mit Geldstrafe bestraft.
Para. 156 StGB (German Criminal Code): False Statutory Declarations
Whoever before a public authority competent to administer statutory declarations falsely makes such a declaration or falsely testifies while referring to such a declaration shall be liable to imprisonment not exceeding three years or a fine.
§ 161 StGB: Fahrlässiger Falscheid; fahrlässige falsche Versicherung an Eides Statt
(1) Wenn eine der in den §§ 154 bis 156 bezeichneten Handlungen aus Fahrlässigkeit begangen worden ist, so tritt Freiheitsstrafe bis zu einem Jahr oder Geldstrafe ein.
(2) Straflosigkeit tritt ein, wenn der Täter die falsche Angabe rechtzeitig berichtigt. Die Vorschriften des § 158 Abs. 2 und 3 gelten entsprechend.
Para. 161 StGB (German Criminal Code): False Statutory Declarations Due to Negligence
(1) If a person commits one of the offences listed in sections 154 through 156 negligently the penalty shall be imprisonment not exceeding one year or a fine.
(2) The offender shall be exempt from liability if he or she corrects their false testimony in time. The provisions of section 158 (2) and (3) shall apply accordingly.

Die vorstehende Belehrung habe ich zur Kenntnis genommen:
I have read and understood the above official notification:

Aachen, 18.04.2023
Ort, Datum/City, Date

Unterschrift/Signature

Contents

List of Figures

List of Tables

Abstract

In recent times, sedentary lifestyles and prolonged sitting have become increasingly common among office workers. This trend has resulted in a rise in the prevalence of back pain and other musculoskeletal disorders. Therefore, sitting posture guidance has become a critical area of research. Unhealthy sitting habits are not solely defined by a specific posture but rather by static sitting, which occurs when people remain seated in one position for extended periods without movement. This is especially prevalent among those preoccupied with their primary computer task. For this purpose, we have developed a non-interrupting peripheral feedback system for sitting posture guidance. The system uses an anthropomorphic figure to provide feedback when the user has remained in a static sitting position for an extended period, encouraging users to adopt more dynamic sitting habits. To evaluate the effectiveness of our system, we conducted a user study to determine if there was a difference in the performance of the primary task (computer work) or the secondary task (posture monitoring) depending on the cognitive load of the primary task or whether the feedback animation incorporated continuous movement. Our results show that the system works as intended, helping users to perform dynamic sitting without significantly interrupting the primary task. However, we found no significant difference in the performance of the primary and secondary tasks depending on the movement and no significant difference in the performance of posture monitoring depending on the cognitive load. Through this thesis, we present a practical solution for individuals seeking to improve their sitting posture in a non-intrusive way.

Überblick

In den letzten Jahren ist eine sitzende Lebensweise mit langen Sitzzeiten immer häufiger geworden, insbesondere bei Büroangestellten. Dieser Trend führt zu einem Anstieg von Rücken- und Muskelskeletterkrankungen und macht daher die Haltungsforschung zu einem wichtigen Forschungsbereich. Ungesunde Sitzgewohnheiten sind nicht nur durch eine bestimmte Haltung definiert, sondern vor allem durch das statische Sitzen über längere Zeit ohne jegliche Bewegung. Dies trifft vor allem auf Personen zu, die stark auf ihre Hauptaufgabe am Computer konzentriert sind. Daher haben wir ein peripheres Feedbacksystem entwickelt, das kontinuierlich die Sitzhaltung überwacht und den Nutzer mittels einer anthropomorphen Darstellung auf eine dynamischere Haltung aufmerksam macht. Wir haben eine Nutzerstudie durchgeführt, um die Effektivität des Systems zu evaluieren und festzustellen, ob es einen Unterschied in der Leistung der primären Aufgabe (Computerarbeit) und der sekundären Aufgabe (Überwachung der Körperhaltung) gibt, je nach kognitiver Belastung und danach, ob die Feedback-Animation kontinuierliche Bewegung beinhaltet oder nicht. Unsere Ergebnisse zeigen, dass unser System Nutzern erfolgreich dabei hilft, dynamisch zu sitzen, ohne ihre Hauptaufgabe zu beeinträchtigen. Wir haben jedoch keinen signifikanten Unterschied in der Leistung beider Aufgaben festgestellt, abhängig von der Art der Animation und keinen Unterschied in der Leistung der Haltungskontrolle abhängig von der kognitiven Belastung. Insgesamt bieten wir mit unserer Arbeit eine praktische und nicht-intrusive Lösung an, um die Sitzhaltung von Personen zu verbessern.

Acknowledgements

I would like to extend my sincere thanks to Prof. Dr. Jan Borchers and Dr. Jörg Eschweiler for allowing me to work on this thesis as a collaborative project and for examining it.

Special thanks go to my supervisors René Schäfer and Dr. Maximilian Praster. I appreciate the safe and comfortable environment you provided, where I could share my ideas and receive your observant and helpful feedback.

I am also grateful to the i10 chair staff and the Institute of Orthopedics Trauma and Reconstructive Surgery, particularly Dr. Hannah Siebers, for her mentorship, encouragement, and passion for research. Your guidance and expertise have been invaluable in shaping my understanding and approach to motion analysis and research.

I want to express my deepest gratitude to Joachim, Martin and Huyen for proofreading this thesis.

The willingness of each of the 25 study participants to contribute their time made this thesis possible. I am grateful for their contribution.

Finally, I would like to express my heartfelt appreciation to my better half, Dima, for his support, patience, and understanding throughout my studies. Your love, tea, warming bottles, and hugs have sustained me during the long hours of writing.

Conventions

Throughout this thesis we use the following conventions.

Text conventions

Definitions of technical terms or short excursus are set off in coloured boxes.

Excursus:
Excursus are detailed discussions of a particular point in a book, usually in an appendix, or digressions in a written text.

Definition:
Excursus

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

`myClass`

The whole thesis is written in Canadian English.

Throughout this thesis we use the gender-neutral pronoun *they* to include people of any identity

Throughout the course of this master's thesis, it should be noted that Xsens underwent a rebranding process as a part of Movella. Therefore, in this work, we will utilize the name Xsens to refer to the Movella products.

Chapter 1

Introduction

Back pain is a prevalent issue in modern society, attributed mainly to the increase of sedentary office jobs [Bontrup et al., 2019]. Musculoskeletal symptoms of the spine are widespread in office workers [Janwantanakul et al., 2008], with low back pain causing the majority of global disabilities in people under 45 [Hoy et al., 2014].

Prolonged sitting is common in modern society and can cause disabilities of the spine

Traditional education on proper posture, such as encouraging to keep a straight spine, may be insufficient in promoting healthy posture among individuals, as it does not provide real-time feedback. This lack of feedback contributes to individuals being unaware of their poor posture during periods of high workload [Daian et al., 2007]. To address this issue, feedback systems have been proposed as a solution, e.g., visual feedback [Daian et al., 2007, Kim et al., 2016, Hong et al., 2015b, Wölfel, 2017], auditory feedback [Daian et al., 2007, Takayama et al., 2021] and tactile feedback [Park et al., 2016, Zheng and Morrell, 2010]. However, these systems can cause interruption in the primary task of an individual, potentially leading to frustration and reluctance to use such systems [Horvitz et al., 2001].

Previously presented feedback systems may cause interruption in the users' work

Definition: *Primary Task*

Primary Task:
during a dual-task setup of computer work and concurrent posture monitoring, the primary task corresponds to the task of higher priority that is receiving the most attention. In our case it refers to computer work

Recent findings suggest that there is no "optimal" sitting posture. Dynamic sitting might be a more important factor in spinal health

Previous work established their feedback prototypes primarily on the notion of a single "optimal" sitting posture, which is usually defined as a neutral spinal position, e.g., [Zheng and Morrell, 2010, Taylor et al., 2013, Duffy and Smeaton, 2013]. Deviations from that "optimal" position trigger the feedback. However, recent trends in literature show that musculoskeletal symptoms of the spine primarily stem from static sitting and sitting duration in general and less from the spinal posture that is assumed [Bontrup et al., 2019, Womersley and May, 2006]. Additionally, there is no clear consensus on what the "optimal" posture might look like. Physiotherapists seem to agree that positions that deviate most from the neutral shape of the spine might be the most harmful ones [O'Sullivan et al., 2012].

A peripheral display might work as a less intrusive means of sitting posture feedback

One potential solution to minimize interruption is using peripheral visual feedback on a secondary display. This principle assumes that the brain may process peripheral vision as a separate sensory channel from central vision [Leibowitz et al., 1984] and is therefore not restricted by the limited multitasking ability concerning information from the same cognitive resource [Wickens et al., 2015]. Previous scientific work suggests a temporary reduction of information intake from the peripheral vision during high workload in the central field of vision or if the user is already under stress [Stokes et al., 1990, Williams, 1995], also known as *tunnel vision*. By taking advantage of this phenomenon it could be possible to offer feedback to a user in peripheral form without interrupting them during high workload scenarios, reducing user frustration.

It is questionable if peripheral feedback would benefit from continuous movement or static animations

Although design guidelines for peripheral information exist [Bartram et al., 2003], it is still unclear if peripheral feedback should incorporate continuous movement. Continuous movement can help the feedback to have better adaptability into the users' environment, strengthen the decorative perception of the feedback [Parkes et al., 2008, Birnholtz et al., 2010], (see kinetic desk decor in Figure 1.1, e.g., lava lamps, newton's cradle, moving sand art) and increase noticeability [Bartram et al., 2003]. A downside to peripheral feedback with continuous movement is that it may be more distracting than feedback that only moves between states [Mairena et al., 2019]. For the design of a posture feedback system it is important to find out to what extent continuously moving animations are distracting in this scenario and whether it is worth integrating them for increased aesthetics and conspicuousness.

Peripheral feedback is perceived as less intrusive than central feedback

The advantage of peripheral displays over central displays or pop-up windows has already been shown [Haller et al., 2011, Costanza et al., 2006, Lee et al., 2020]. It remains to analyze if peripheral feedback for sitting posture guidance performs differently if the primary task has low or high cognitive demand during a similar task structure and if there is a perceived difference between peripheral displays that incorporate continuous movement compared to a static image during the practice of dynamic sitting.

The incorporation of calm and persuasive technology concepts may enhance the acceptance of feedback

The research field of peripheral feedback is closely related to calm or ambient and persuasive technology. Calm technology naturally integrates into the users' environment, reducing distraction and mental effort [Wölfel, 2017]. Additionally, persuasive technology can increase motivation and build habits [Orji and Moffatt, 2018]. There has already been research proposing various prototypes in the form of anthropomorphic flowers [Hong et al., 2015b, Haller et al., 2011] or animals [Khurana et al., 2014].

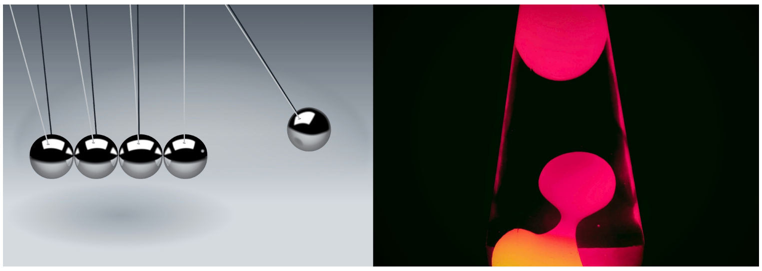

Figure 1.1: Newton's cradle (left) and lava lamp (right), examples for kinetic desk decor. Images from pexels.com

Definition: *Anthropomorphism*

ANTHROPOMORPHISM:
the attribution of human characteristics or behaviour to a god, animal, or object.
– Oxford English Dictionary

We want to find out if the performance of peripheral feedback changes depending on the cognitive load of the primary task and to evaluate moving and static animations during dynamic sitting

To pick up on the idea of an anthropomorphic plant, we create a peripheral sitting posture feedback prototype and evaluate its perception. This work aims to determine the impact of peripheral feedback on interruption and task performance between tasks of high and low mental load and investigate the difference between peripheral feedback with continuous movement and feedback that only moves between two states. In contrast to previous literature that defined a single "optimal" posture, we analyze these effects during dynamic sitting, which incorporates frequent posture changes.

Chapter 2

Background

2.1 Medical Definitions

In order to increase the understanding in the further course of the work, we will introduce medical terminology here to facilitate the description of anatomical positions and movements of the human body.

Human body movements are characterized by the planes or axes they occur on

The three primary planes that intersect the human body are the sagittal, frontal, and transverse planes. The sagittal plane divides the body vertically from front to back, along the frontal axis, into left and right sides. The frontal plane divides the body horizontally from left to right, along the transverse axis, into front and back portions. The transverse plane divides the body horizontally along the sagittal axis into upper and lower parts, from the trunk to the head and from the groin to the toes. Examples of movements along the frontal axis include leaning forward or backward, while rotations of the trunk, such as looking backward, are movements along the longitudinal axis. Bending sideways or raising one arm sideways are examples of movements along the sagittal axis. See Figure 2.1 for an illustration of these planes.

We describe positions by their medical directional references

Directional references help to precise the location and direction of e.g., movements or organs on the human body. Figure 2.2 shows a representation of the most important di-

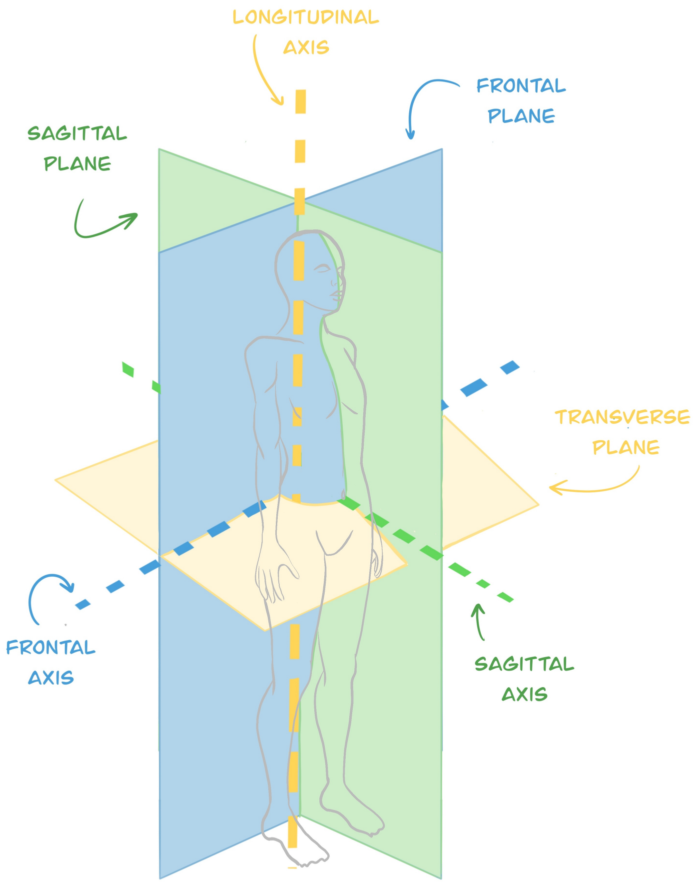

Figure 2.1: Anatomical terms of location: Planes and axes. Movements of the body are described by referring to activities on a plane or around an axis. Figure content is referenced from: The FARLEX Medical Dictionary[1]

rectional references. Throughout this work, we will utilize terminologies such as anterior (indicating closer proximity to the front of the body) and posterior (referring to proximity to the back of the body), as well as superior (referring to the top of the body) and inferior (referring to the bottom of the body) to describe directions.

---

[1] https://medical-dictionary.thefreedictionary.com/plane *(Accessed on 10.04.2023)*

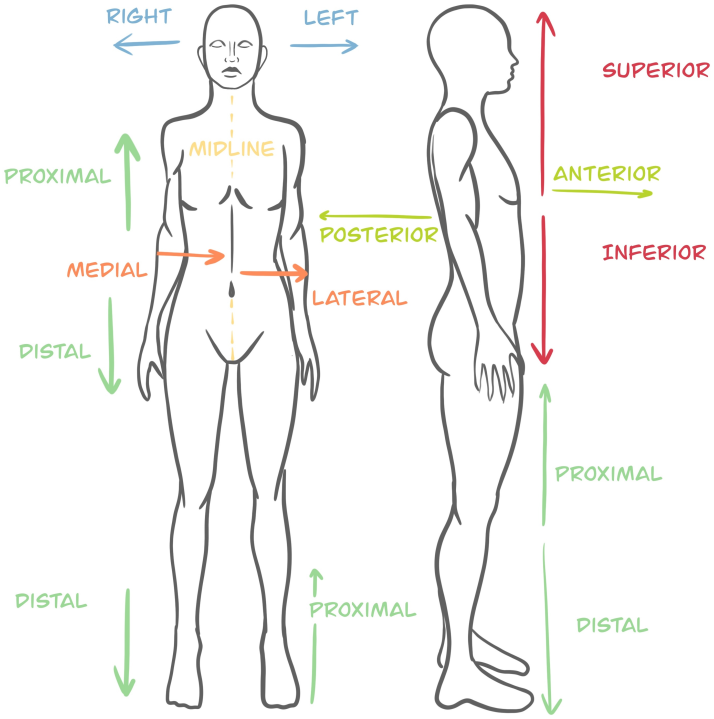

Figure 2.2: Anatomical terms of location: Directional references. In the medical field, locations or directions on the human body are referred to by directional references. Figure content is referenced from: Medic Tests[2]

2.2 The Spine

The information presented in this chapter is based on the textbook: "*Clinical Anatomy of the Spine, Spinal Cord, and Ans*" [Cramer, 2014].

The spine performs several critical functions, including providing structural support for the body, protecting the spinal cord, and facilitating trunk movements.

Four curved regions define the shape of the spine

The spine comprises four distinct regions, cervical region, thoracic region, lumbar region, and sacrum, arranged from

---

[2] https://medictests.com/units/standard-anatomical-terms-and-planes *(Accessed on 10.04.2023)*

superior to inferior. The spine's shape is determined by four curves, including two kyphoses and two lordoses. A kyphosis refers to a convex curvature when the anterior aspect of the human body is considered as the reference point, while a lordosis describes a concave curvature in the same context. The main kyphosis in the spine is present in the thoraical region while the main lordosis is located in the lumbar spine. The cervical region has a minor lordosis, and the sacrum has a minor kyphosis. The curves give the spine its typical s-shape, that it assumes in a neutral position and that helps to absorb loads that may affect the spine. We will refer to this s-shaped neutral posture as the natural or neutral posture of the spine in this work. See Figure 2.3 for an illustration of the spinal regions.

The spine consists of vertebrae and intervertebral discs

The 24 movable bone fragments of the spine are called vertebrae. Each vertebra consists of a vertebral body, which supports the weight of the human body and additional loads and a vertebral arch, which among other things, encloses the spinal cord. The vertebrae are connected by the vertebral bodies, with intervertebral discs between each bone (except between C1 and C2) enabling flexibility and load support of the spine. There are seven cervical (C) , twelve thoracic (T) , five lumbar (L) and five sacral (S) vertebrae. During adulthood the five sacral vertebrae fuse to form the sacrum and the most inferior vertebrae form the coccyx. Each of the vertebrae are identified by the location in the spine (C, T, L or S) and the corresponding number, which is counted from superior to posterior (e.g., T5 is the fifth vertebra in the thoracic region of the spine).

2.3 The Eye

The following two paragraphs reference information from the textbook "*Augenheilkunde*" [Grehn and Leydhecker, 2012].

Human vision works by light falling on an object and being reflected by it, hitting the human eye. A schematic cross-section of the human eye can be found in Figure 2.4. The translucent cornea focuses the reflected light, which sub-

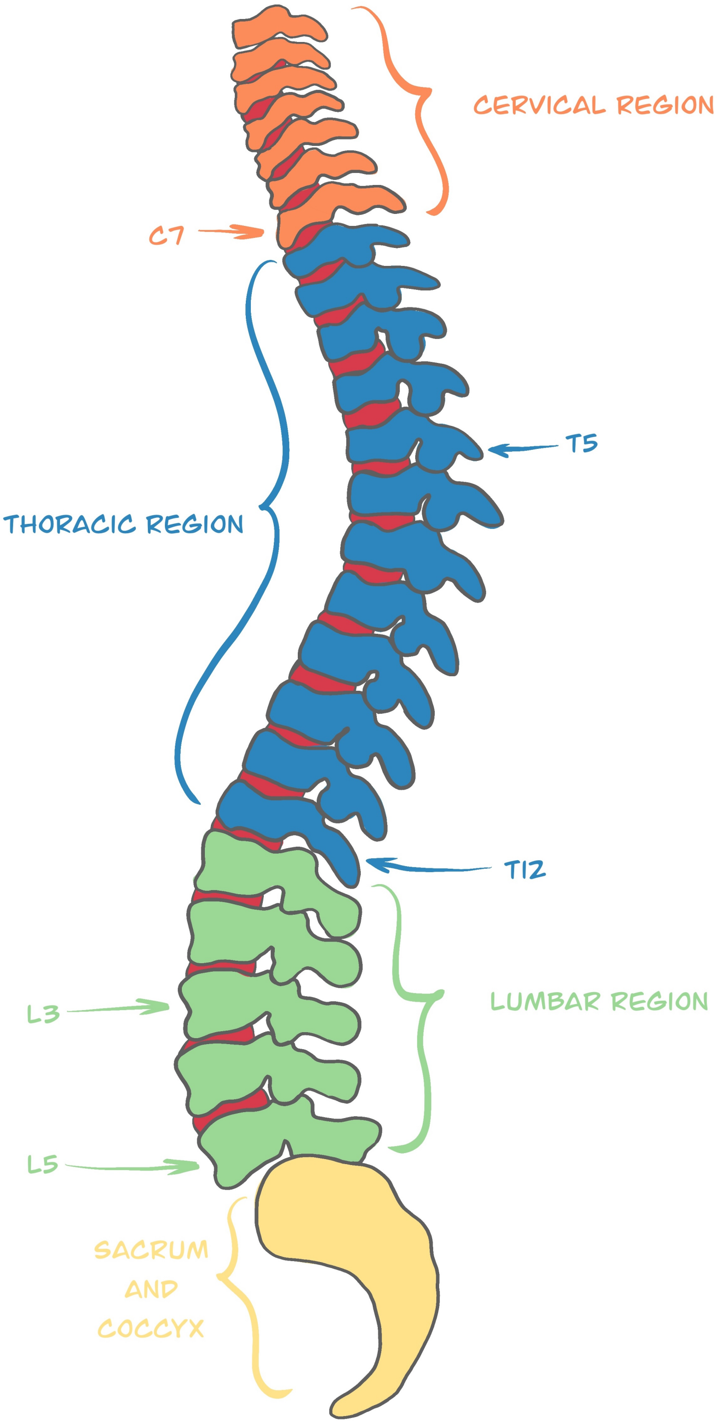

Figure 2.3: Schematic illustration of the spine. It shows four curves in the neutral posture.

Human vision works by light falling into the eye and reaching the retina, where it is received by the photoreceptors

sequently passes through the iris. The iris works as a diaphragm in the eye and changes the size of its opening (the pupil) to control the amount of light that can enter it. In bright light conditions, the pupil constricts, while in dim light, it dilates to allow more light to enter. The lens, located behind the pupil is responsible for refracting the light so that it is focused and reaches the retina, thus creating a sharp image. On its way to the retina, the light passes through the vitreous. The retina acts as the sensory part of the eye and is located at the back of the eyeball. It is a part of the brain that has been pushed forward during evoultion and contains about 127 million photoreceptor cells that enable vision.

2.3.1 Photoreceptors and Peripheral Vision

Central and peripheral vision is enabled by rods and cones respectively

There are two groups of photoreceptor cells in the retina, cones and rods. The central part of the retina mainly con-

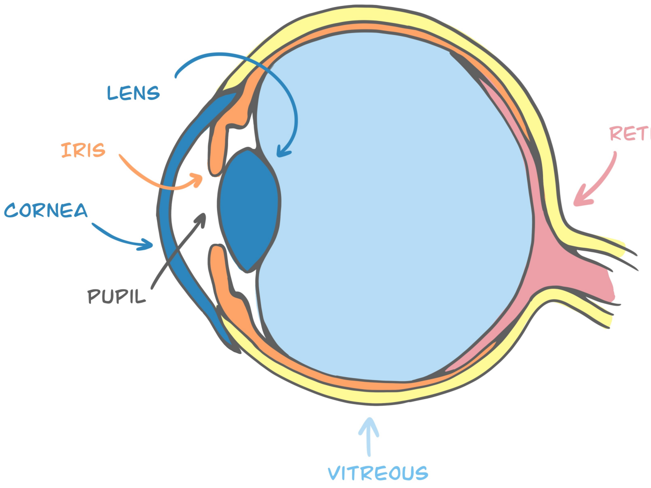

Figure 2.4: A Schematic Cross-section of the Eye. Light passes through cornea, lens and vitreous before reaching the retina, where the photoreceptors are located. Figure content is referenced from Grehn and Leydhecker [2012].

sists of cones. These are responsible for color vision and day vision, while the rods in the periphery of the retina enable twilight vision and night vision. The peripheral visual field is crucial for perceiving movements and orientation, and it is more sensitive to such stimuli than the central visual field. However, the central visual field provides sharper vision, which is not present in the peripheral field.

Peripheral detection of movement has acted as an evolutionary advantage to quickly detect objects or predators

Evolutionary biology has resulted in the development of a visual system that can rapidly detect potential threats or stimuli from the periphery, and when attention is redirected in that direction, the details of the object can be perceived with high resolution [Horridge, 1987, Schmidtmann et al., 2015]. Therefore, diseases affecting the central retina may result in reduced sharpness of vision but preserved orientation abilities, whereas damage to the peripheral retina can lead to the opposite effect [Grehn and Leydhecker, 2012]. When there is a high workload in the central field of vision, or a person is subjected to stress, peripheral vision is briefly reduced, also known as “visual field narrowing” or “tunnel vision” [Williams, 1995, Stokes et al., 1990].

Sensory channels have limited capacity. Peripheral vision can act as a separate channel from central vision

Only a limited amount of information can be processed through one sensory channel at a time [Mayer et al., 2001]. If a sensory channel is already in use, e.g., the visual channel while doing computer tasks and looking at the display, then this channel should not be overloaded with more information. Instead, the information should be delivered through a different sensory channel, such as auditory or haptic channels through notification tones or vibrations. However, some psychological literature suggests that the visual channel can be divided into two different categories. The central vision and the peripheral vision. The peripheral vision is interpreted as a sensory channel that exists separately, but not independently, from the central vision, and can therefore receive additional information that will not interfere as much with the information in the central vision [Leibowitz et al., 1984].

2.4 The MTw Awinda System

The Xsens MTw Awinda is a validated inertial measurement system

The Xsens MTw Awinda system (by Movella Inc.) is an Inertial Measurement Unit (IMU) motion capture system, that has been validated in various studies e.g., [Zhang et al., 2013, Benjaminse et al., 2020]. In the further course of this work we will refer to the Xsens MTw Awinda System as "Awinda". The system synchronizes up to 18 wireless inertial sensor units that enable dynamic joint angle measurement with an accuracy of under 1.5° RMS, based on the companies information (see MTw Awinda Website[3]).

IMUs consist of accelerometer, gyroscope and magnetometer to enable measurement in nine degrees of freedom

Inertial measurement units are devices, able to measure velocity, orientation and gravitational force and usually consist of accelerometers (to measure velocity) and gyroscopes (to measure orientation) resulting in six degrees of freedom (see Figure 2.5). Some IMUs, like the Awinda sensors, have an additional magnetometer, which measures the yaw angle rotation. This results in theoretical "nine degrees of freedom", when magnetometer, gyroscope and accelerometer track tri-axial data [Ahmad et al., 2013]. Joint angles are calculated by the relationship of the two IMUs that are located on the segments enclosing the joint. The Awinda measures angular velocity with an accuracy of ± 2000 deg/s, acceleration with ± 160 m/s and the magnetic field with ± 1.9 Gauss in three axes.

The sensors are attached to the body through velcro straps and Xsens accesoires

Each sensor measures 47x30x13 mm, weights 16 g and has a battery life of up to six hours. The sensors for upper leg, lower leg, pelvis, upper arms and forearms are fixated on the body parts with velcro straps (see Figure 2.6). Feet sensors are applied to insoles that are inserted in shoes or socks, hand sensors are placed into fingerless gloves, the sternum and shoulder sensors can be fit onto the Xsens t-shirt and the head sensor is placed into a headband.

Awinda measurements can be managed with the MVN Analyze software

The MTw Awinda sensor system has a wide range of applications, such as in virtual reality, simulation for game development, ergonomics, and gait analysis research. The measurement data can be analyzed using the MVN Ana-

---

[3] https://www.movella.com/products/wearables/xsens-mtw-awinda *(Accessed on 10.04.2023)*

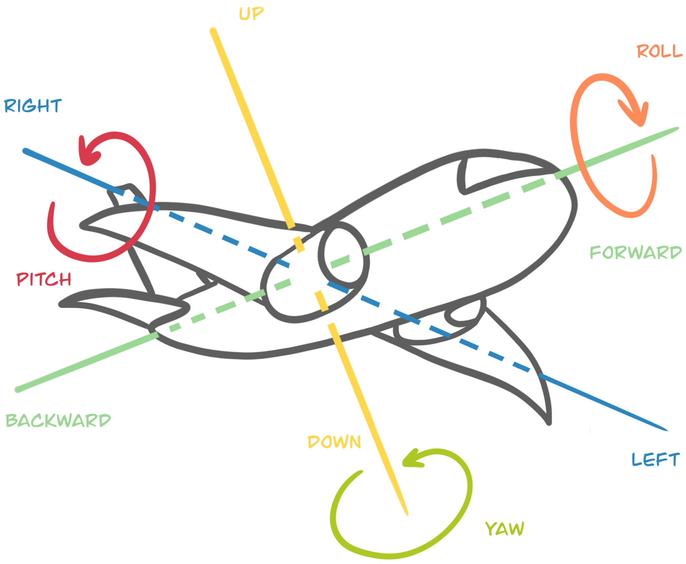

Figure 2.5: Six degrees of freedom illustrated on the example of an airplane. IMUs are capable of measurements in the depicted parameters. Figure content is referenced from Wikipedia[4]

lyze software, which is compatible with Windows operating systems. The sensor data is synchronized and transmitted to the software via USB/Ethernet port through the Awindas docking station. With a sampling rate of 100 Hz, the sensors can be used to take measurements up to 20 m away from the docking station.

When starting a measurement, we have to set initial configurations

To initiate a measurement using the motion capture system, the user must create a new motion capture within the software via the ”File” tab. This opens a window in which various parameters must be configured, such as the measurement system, the measurement configuration (e.g., whole body, upper or lower body), maximum sampling rate, and scenario (e.g., single level, multiple levels). The height and foot length of the subject, as well as any necessary props, can also be specified. Limb lengths may be optionally stated for greater accuracy. A representation of the human body is displayed on the right side of the screen, with

---

[4] https://en.wikipedia.org/wiki/Euler_angles *(Accessed on 14.04.2023)*

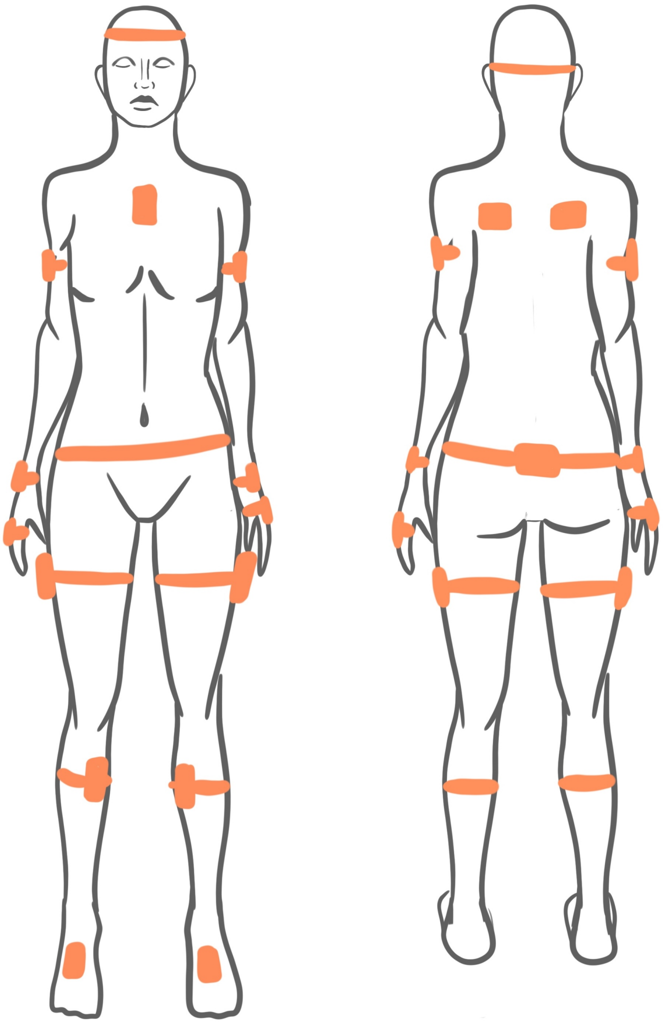

Figure 2.6: The location of the Awinda sensors on the human body in the full-body configuration. Each body segment is equipped with one IMU to enable joint angle measurements.

synchronized sensors lighting up in green at corresponding positions. Sensors that cannot be located are shown in gray. Once all the necessary information and the storage location and name are entered, a calibration should be performed (see Section 5.7).

Each angle of the spinal section is described by three outputs, representing *Lateral Bending*, *Axial Bending* or *Rotation*, and *Flexion/Extension*, with *Axial Rotation* being output for all joint angles in the spinal segment except for the L5S1 angle, which outputs *Axial Bending*. These parameters follow the *XZY* specifications. The specification *X* or *Lateral Bending* relates to movement on the frontal plane or around the sagittal axis, representing lateral bending of the back to the left or right. This type of movement occurs, for example, when adjusting the seat height of a desk chair by manipulating the lever under the chair. The specification *Z* or *Flexion/Extension* refers to movement on the sagittal plane or around the transversal axis, which includes bending forward or stretching backward, such as when picking up an object. *Flexion* is indicated by numbers with a positive sign, while *Extension* is represented with a negative sign. The specification *Y* or *Axial Rotation/Bending* corresponds to movement on the transverse plane or around the longitudinal axis, which encompasses rotations of the spine that occur when attempting to look backward.

Awinda puts out parameters lateral bending, axial bending and flexion/extension for the relevant joints

Chapter 3

Related work

Due to the prevalence of office jobs in recent times, the research on sitting posture and posture guidance has been extensive. We will give an overview over sitting posture and problems arising from prolonged sitting as well as recommendations to minimize negative effects. Afterwards we present various sitting posture recognition approaches and possible feedback modalities. Finally we will look into calm technology and peripheral feedback as a means to guide posture with reduced interruption.

3.1 Sitting Posture and the Effects of Prolonged Sitting

There is no clear scientific consensus on the definition of an ″optimal″ sitting posture. However, researchers agree that maintaining a spinal position that closely resembles the natural shape of the spine is the most protective posture when sitting, particularly when combined with frequent changes in sitting positions [Kastelic et al., 2018].

Changing the sitting posture frequently and assuming a neutral spinal position protect the spinal health

3.1.1 Low Back Pain

Office work leads to increased occurrences of lumbago

Low Back Pain (LBP) is the most common musculoskeletal issue in the general population, and half of the people suffering from at least one case in their lifetime experience chronic symptoms [Kastelic et al., 2018]. According to Yamada et al. [2020], the occurrence of lumbago (extreme muscle soreness in the lumbar spine) is increasing in young office workers. Yamada et al. [2020] have found that office workers that suffered from headaches or lumbago had a significantly larger spinal distortion than those that did not suffer from above symptoms during office work.

Most causes of LBP stem from a prolonged, static sitting posture

Kastelic et al. [2018] describe various causes for LBP. They portray sitting as a widely accepted risk factor. Although the spine is only exposed to low loads during sitting, the resistance of spinal tissues to the loads is reduced when there is no interruption in exposure. According to Kastelic et al. [2018], optimal spinal health is achieved when tissues are subject to mostly dynamic loads, which is not given during static sitting. Static sitting can also cause disc dehydration, accelerating the degeneration of the spinal discs. The low muscle activity that results from static sitting can lead to less oxygenation of the muscles. Another source of pain can stem from the slow progression of disc hernia (injury to the connective tissue between vertebrae). Slouched sitting amplifies this, which leads to the assumption that a neutral spine position is favourable [Kastelic et al., 2018]. Vergara and Page [2002] found that lower back pain during prolonged sitting often stems from a lordotic posture of the lower back and a forward tilt of the pelvis and recommend frequent movement to help reduce symptoms.

There is no general, scientifically backed up guideline for sitting posture

Kastelic et al. [2018] criticize that no authoritative organization publishes ergonomic sitting recommendations and that substantial differences exist between recommendations. The fact that the market is overflowing with allegedly ergonomic chairs and other accessories, with no scientific evidence to support them, reinforces the problem of missing recommendations.

3.1.2 Chronic Neck Pain

Chronic neck pain is a condition that is gaining prevalence [Hoy et al., 2014]. Evidence shows a correlation between neck pain and a flexed neck posture [Ariëns et al., 2001]. Using computers and mobile display devices often leads to cervical spine flexion that can act as a risk factor for chronic neck pain [Barrett et al., 2020, Straker et al., 2009, Bonney and Corlett, 2002, Cuéllar and Lanman, 2017]. Due to the recent rise in the popularity of cell phones, there is a higher association of forward head posture with mobile phone usage [Guan et al., 2016, Lee et al., 2015]. Park [2015] recommend having a retracted neck position during neutral sitting due to the overstress in the C6-7 segment of the cervical spine that can lead to degeneration of the spinal segments.

A flexed position of the cervical spine often causes chronic neck pain

Barrett et al. [2020] have investigated the compression and shear forces that press on the neck in 45° of flexion and neutral neck positioning. Guan et al. [2016] and Lee et al. [2015] determine an angle of 45° as a typical degree of neck flexion that occurs during the usage of mobile phones. Barrett et al. [2020] have found that the compression increased twofold (in the cervical spine), and the anterior shear increased fourfold (in the upper cervical spine) during the 45° neck flexion. Although Schmidt et al. [2013] found a significant anteroposterior shear to act as a risk factor in disc herniation, Barrett et al. [2020] have not found shear forces that are as large as needed for disc herniation and therefore assume that prolonged neck flexion is responsible for the occurrence of chronic neck pain rather than a single loading event.

Compression and shear forces in the cervical spine increase significantly with flexed neck position

However, Richards et al. [2021] have found that a slumped cervical neck posture during late adolescence did not act as a risk factor for persistent neck pain in adulthood. On the contrary, it even acted protective against persistent neck pain in female participants.

A slumped neck posture is not a risk factor for persistent neck pain

3.1.3 Postural Self-Correction

Lumbar spine corrections might require active feedback

Barczyk-Pawelec and Sipko [2017] have investigated if active self-correction improved women's posture. They have found that self-correction led to different results depending on standing or sitting posture. During active self-correction while in a sitting posture, the movement mainly occurred in the upper part of the thoracic spine. The findings conclude that correction of the lumbar spine might only be achievable through active feedback and instruction but not self-correction.

During self-correction spine angles approach the neutral standing posture

Claus et al. [2016] investigated spine angles during a ten-minute computer task with habitual posture, during a ten-minute computer task with self-corrected posture and during standing. They found that a lordotic posture of the lumbar spine was rarely present (it was either flat or slumped) during the computer task. However, a lordosis of the lumbar spine is mainly regarded as the optimal posture due to the spine's natural curves. When the participants self-corrected, the spine angles became closer to the angles during a standing position. The thoracolumbar angle replicated the standing position while the lumbar angle moved midway to the angle during standing.

Individuals do not believe that they have optimal posture and have different understandings of it

Although Korakakis et al. [2021] found that none of their participants believed that their habitual sitting posture was optimal, it can not be deducted that users are competent in self-correcting their posture as Edmondston et al. [2007] suggest that people suffering from neck pain may have a different understanding of a good posture compared to asymptomatic people.

3.1.4 Strategies for Maintaining Spinal Health

Stretching of the hip flexors may help to protect the spine

Prolonged sitting is associated with reduced flexibility of hip flexors, leading to strain in the lumbopelvic area and increasing the risk of lower back injury [Kastelic et al., 2018]. Lee et al. [2021] recommend periodical stretching of the hamstrings to help achieve lumbar spine lordosis for office workers who must sit for extended periods.

Kastelic et al. [2018] propose small movements of the trunk, frequent changes in sitting position and generally increased levels of physical activity to prevent spinal tissue overload, disc dehydration and muscular issues. We present the concluded recommendations from Kastelic et al. [2018] in Figure 3.1.

Frequent changes in sitting position and physical activity are recommended to reduce adverse effects of prolonged sitting

Adopting a "neutral" spine position during sitting may be challenging because the appearance of a neutral posture is usually defined in an upright standing body. An upright sitting position causes a decrease in the lumbosacral curve compared to an upright standing position [De Carvalho et al., 2010]. Claus et al. [2009] found that the participants in their study had difficulties maintaining a lumbar lordosis during sitting.

The definition of a "neutral" position of the spine can not be easily transferred to sitting

Tahernejad et al. [2022] defined a recommendation of maximum holding times for various postures based on 20% of discomfort relative to the maximum discomfort tolerance. Their recommendations ranged from a maximum of 1.61 to 2.37 s for various neck postures and 1.78 to 5.92 s for trunk postures. A neutral neck posture and a supported backward trunk position could be held longest.

The maximum recommended holding time for various postures ranges from 90 seconds to 5 minutes

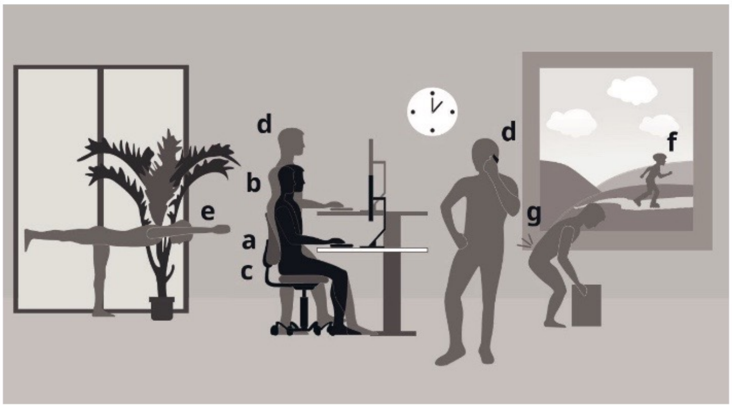

Figure 3.1: Sitting recommendations include neutral spinal curves (a), dynamic sitting (b), the reduction of loads (c), frequent movement apart from the chair (d,e,f) and refraining from heavy labour after prolonged sedentary time (g). Image from [Kastelic et al., 2018].

3.1.5 What Do Physiotherapists Consider to Be the Best Sitting Spinal Posture?

O'Sullivan et al. [2012] conducted a study where they presented nine images (see Figure 3.2) of different spinal postures to 296 physiotherapists from four European countries (Ireland, England, Germany and the Netherlands). The images represented various degrees of spinal flexion and extension. The physiotherapists were asked to rate the nine presented postures from best to worst and to fill out a Back Reliefs Questionnaire (BRQ).

European physiotherapists prefer sitting postures that reflect the neural shape of the spine, with slight lordosis of the lumbar spine and kyphosis of the thoracic spine

Only one of the physiotherapists reported that all of the presented postures were acceptable due to the inexistence of an "optimal sitting posture". Other than that, most physiotherapists chose postures five and nine as the "ideal posture". Posture nine is defined by a neutral spinal position, with slight lumbar lordosis and a relaxed, slightly kyphotic thoracic spine. The physiotherapists justified their decision by proclaiming that this posture represented the natural form of the spine and looked relaxed. This follows other studies showing that a relaxed posture [Richards et al., 2021] and the natural posture of the spine [Kastelic et al., 2018] are beneficial for spinal health. However, the physiotherapists criticized the ninth posture's relatively high flexion of the cervical spine. Posture five reflects a lumbar and thoracic spine extension and a general torso flexion. The very slight lordosis of the lumbar spine, relaxed posture and head to spine alignment were rated positively. However, flexion of the torso and the fact that the lordosis was too slight in the lumbar spine were seen negatively. Although posture five was the most favoured by physiotherapists in Germany, it was chosen significantly less often than the ninth posture (see Table 3.1).

3.2 Posture Recognition

Much literature uses the same ten reference postures for sitting posture classification

Various methods have been proposed for posture recognition, each with advantages and limitations. In their study, Tan et al. [2001] put forward a set of ten frequently ob-

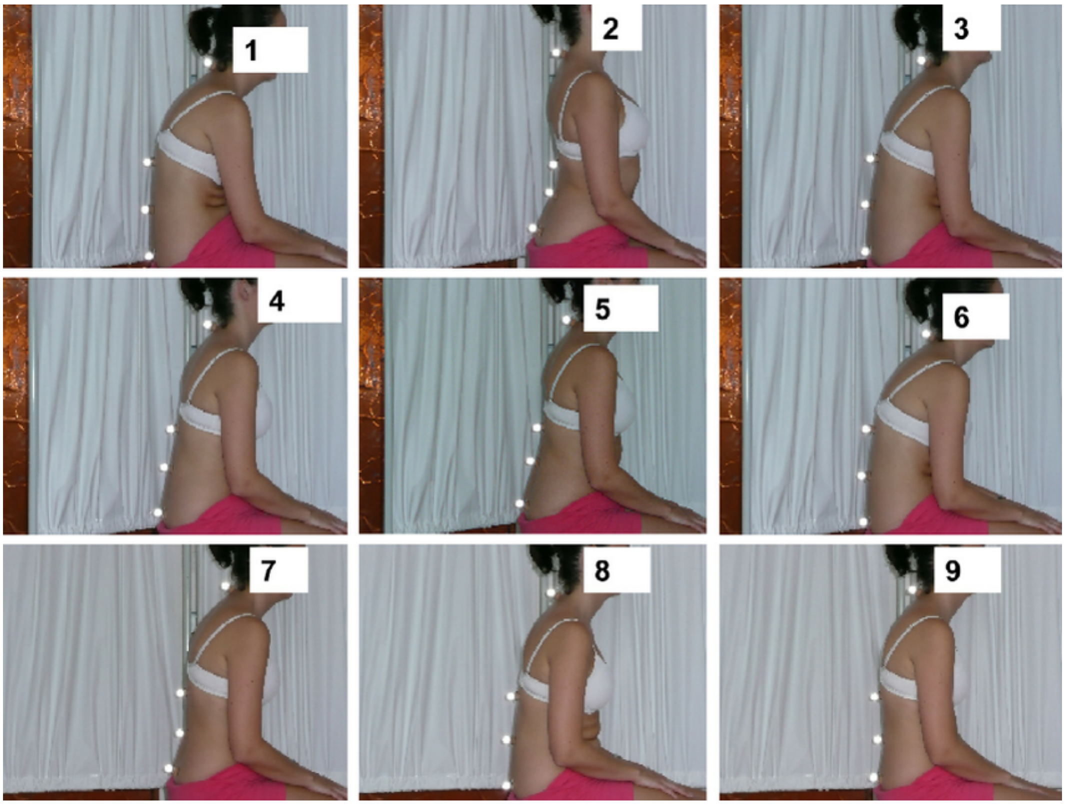

Figure 3.2: The nine sitting posture options from [O'Sullivan et al., 2012]. Physiotherapists preferred postures five and nine while postures one, six and seven were perceived worst.

Posture selected	England (n = 88)	Ireland (n = 110)	Germany (n = 41)	Netherlands (n = 56)	Overall (n = 295)
1	0	0	0	0	0
2	1.1	6.4	12.2	5.4	5.4
3	1.1	0	2.4	1.8	1.0
4	4.5	3.6	7.3	8.9	5.4
5	28.4	26.4	48.8	28.6	30.5
6	0	0	0	0	0
7	0	1.8	0	1.8	1.0
8	1.1	0	2.4	5.4	1.7
9	63.6	61.8	26.8	48.2	54.9
Total	100	100	100	100	100

Table 3.1: Percentage of physiotherapists who selected each posture as best sitting posture in each country from [O'Sullivan et al., 2012]

served sitting postures in office settings, along with the corresponding posture tracking chair. These postures have since been used as a reference for categorizing sitting positions in several subsequent studies, including Zheng and Morrell [2010] and Martins et al. [2013].

There are various technology for sitting posture estimation

Posture recognition technology utilizes various measurement options such as IMUs [Abyarjoo et al., 2015], optical measurement [Zhou et al., 2014], conductive fabric [Jansen et al., 2018], or pressure sensors on a chair [Daian et al., 2007] to detect and monitor an individual's posture in real-time.

IMUs present a cost-effective option of posture recognition

IMUs are sensors that measure various properties, including orientation, angular rate, and position, using accelerometers, gyroscopes, and magnetometers (see Section 2.4). IMUs present a cost-effective option for posture recognition as they are commercially available in considerably small sizes (Micro-Electro-Mechanical System IMUs), making them accessible to a wide range of users [Petropoulos et al., 2017].

It is possible to use a single IMU for posture recognition. However, accuracy may suffer.

Abyarjoo et al. [2015] utilized a single IMU for posture recognition, which can be attached to any garment using a velcro surface. The system defines a "correct" posture and warns when the user deviates from it by an adjustable level. Placing the sensor on one's back may be inconvenient, especially if the user is not flexible enough. The authors propose future feedback in the form of vibration or sound in an earphone. Tee et al. [2020] also proposed a single IMU for posture monitoring in ophthalmologists at a higher risk of negative side effects due to poor posture. The system uses an optimal straight reference position defined during calibration and can detect deviations from a straight posture, such as leaning forward, backward, right, and left. The prototype, in the form of a harness, is worn on the upper body. However, calibrating such systems while standing straight can lead to inconsistencies, as individuals' perception of an optimal sitting posture varies [Edmondston et al., 2007]. Although a single IMU for posture monitoring is practical due to its affordability and accessibility, it may yield less precise posture measurements than information from multiple IMUs combined through sensor fusion.

IMU solutions for recognition of neck posture are also available

Severin [2020] presented a posture recognition prototype that consists of three IMU sensors. The system defines three risk posture factors (Normal, Warning, and Danger) and provides auditory feedback to users when their posture exceeds the threshold. The sensors are embedded in a "cervical belt" (see Figure 3.3) that is worn around the neck like a choker. The benefit of this prototype lies in its ease of application. However, it only considers neck posture and may be uncomfortable to wear daily.

A single IMU sensor can be incorporated in an earphone and act as a feedback device at the same time

The eSense is an IMU designed as a single headphone, positioned in the ear, which provides auditory feedback during forward leaning posture [Takayama et al., 2021]. However, the eSense has not been validated in a user study yet. A comparable approach can be observed in the PosturePal iOS application[1], which employs AirPod data to monitor a user's sitting posture. The app provides auditory and graphical feedback when the user's posture declines to a specific level of slumping, which is customizable. A real-time animated giraffe imitates the user's posture on the phone screen.

Figure 3.3: A cervical belt with three IMUs to measure neck posture. Although it is easy to put on, it might not be applicable for daily measurements due to the lack of comfort and discretion. Image from [Severin, 2020].

---

[1] https://apps.apple.com/de/app/posture-pal-improve-alert/id1590316152 *(Accessed on 10.04.2023)*

Conductive fabric and textile sensors are an alternative to IMUs

In addition to IMUs, prototypes incorporating conductive fabric have also been proposed for posture recognition. Jansen et al. [2018] presented a posture monitoring prototype that utilizes stretchable and disposable tape sensors. These sensors are made of elastic plaster material designed to be attached to the skin to monitor postural changes. Wang [2016] used conductive fabric in posture monitoring garments to detect body posture changes. Similarly, Meyer et al. [2010] presented a prototype that utilized conductive yarn to monitor body posture changes. In addition, textile pressure sensors have been employed to classify sitting postures using sensors on both the backrest and seat [Mutlu et al., 2007] or a pressure sensor chair equipped with integrated force and pressure sensors [Tan et al., 2001, Daian et al., 2007]. Furthermore, an E-Textile cushion has been developed for detecting sitting postures, incorporating capacitive proximity sensors capable of distinguishing up to seven positions. This portable cushion can recognize various postures, such as leaning forward, back, left, and right. However, it may encounter difficulties with postures where the weight distribution remains constant. The cushion utilizes conductive textile materials Rus et al. [2019].

The Microsoft Kinect is a popular choice for optical posture estimation

Apart from those wearable systems, optical technologies have been suggested for estimating posture. The *Microsoft Kinect*[2], an optical motion capture system, has been utilized to estimate standing posture [Zhou et al., 2014, Bucciero et al., 2014], providing real-time 3D estimations of a subject's position by creating projected depth images using an infrared camera. While self-occlusion poses a recurrent challenge in motion analysis of single-depth cameras, the prototype by Zhou et al. [2014] could provide reliable estimations even when the user's body parts were self-occluded. The *Microsoft Kinect* is advantageous for posture estimation due to its ease of setup, portability, and cost-effectiveness. It does not require additional garments compared to wearable technologies such as IMUs.

Smartphone touch sensors can be used to estimate posture based on finger pressure and swipe trajectory

Another approach to detecting posture without additional equipment is by measuring touch interactions. Chudá and Burda [2016] suggested a posture detection system based

---

[2] https://azure.microsoft.com/de-de/products/kinect-dk/ *(Accessed on 10.04.2023)*

on smartphone touch sensors. The system detects finger pressure, swipe trajectory, and time to perform a swipe to estimate the user's posture.

3.3 Automatic Posture Correction

An actuated monitor can balance postures by moving to the opposite site

In their study, Shin et al. [2018] introduced a dynamic monitor animation to induce posture changes by moving the monitor in the opposite direction of unbalanced postures during sitting. This intervention was applied during four different postures: Leaning forward, leaning back, not facing the screen, and tilting the head. The study results showed that the monitor's movement was more distracting during reading and typing tasks than watching a video. The authors suggest this was due to the need to focus on every word while reading and typing. On the other hand, users noticed the motion of the monitor late while watching a video since the video was already moving on its own. Moreover, the authors recommended adjusting the motion parameters of the monitor depending on the user's current activity. In a follow-up study, Shin et al. [2019] extended their prototype from a monitor animation to a dynamic, slow, robotic monitor. The motion of the monitor increased the frequency of non-disruptive corrections of posture and reduced the duration of unbalanced sitting. During the study, the authors also observed different sitting habits of the users. They found that participants had favourite unbalanced postures that mostly involved leaning to one side. The computer display configuration also made participants lean to the side they focused on during a split-screen. They also found that users shifted to an "unbalanced" posture due to being tired and continued to reverse to such a posture after being corrected by the monitor. This leads to the assumption that forced, precisely defined positions do not lead to the desired result but can lead to frustration and annoyance among the users. In Shin et al. [2020], they have additionally observed posture changes that occur in relation to the position of a virtual reality object, expanding their previous research to create design guidelines for posture change by moving virtual objects.

Self-actuating furniture can help meet ergonomic guidelines

In another approach, Wu et al. [2018] proposed ActiveErgo. This personalized and self-actuating furniture senses the user's posture with a *Microsoft Kinect* sensor and adjusts the table and chair to meet ergonomic guidelines. The accuracy and speed of ActiveErgo were found to surpass manual adjustments made by the user. The TiltChair, developed by Fujita et al. [2021], is an innovative chair that dynamically adjusts its inclination angle based on the user's posture. This design aims to challenge the user to maintain their current posture and encourage them to stand up without disrupting their primary task.

The downside of self-actuating furniture is that it does not develop healthy habits

Self-actuating furniture has the ability to assist users in maintaining a correct sitting posture at the moment. However, it lacks in its ability to promote the development of healthy sitting habits in users. By relying solely on self-actuating furniture, users become dependent on it for maintaining a good posture. The ultimate goal, however, is to enable users to have a healthy sitting posture in any environment, regardless of the furniture available. Thus, it is important to develop interventions that help users develop healthy sitting habits that can be applied in any context.

3.4 Feedback

Vibrotactile feedback is effective in sitting posture guidance.

Zheng and Morrell [2010] proposed a vibrotactile feedback chair with pressure sensors and vibration tactors. The tactors would vibrate when the system detected that the user was not sitting in the desired position, defined as upright sitting. Participants sat in an upright posture more often when the vibrotactile feedback was active. Even when the feedback was disabled without their knowledge, they continued to sit upright. This suggests that the vibrotactile feedback approach encouraged a learning effect of posture. In contrast, Ishimatsu and Ueoka [2015] compared the effectiveness of visual and back stimuli feedback during a 30-minute PC session using the *Microsoft Kinect* to detect bad posture. While the back stimuli (stick poking into the user's back) was always noticed, visual feedback (a photograph with two lines showing current and ideal posture) was not and was not needed to adjust posture. Park et al.

[2016] provided an example of tactile feedback using a device that extended from the table, and Tuncer et al.[3] found that their participants preferred vibration over audio and phone notifications as sitting posture feedback. Exler et al. [2019] find similar results in realizing that auditory notifications are annoying in locations where their participants are not alone, which is the case with most office environments.

Visual feedback can be brought to the user in different forms like pop-up windows or monitor brightness

Duffy and Smeaton [2013] investigated the effect of three intervention types on posture using the *Microsoft Kinect* for posture detection. The interventions included monitor brightness, a pop-up window with a posture summary, and a pop-up window with a positive affirmation about good sitting habits. Monitor brightness was the most successful intervention type, with some improvement in the others. Similarly, Goossens et al. [2012] investigated the effect of three interventions (instruction, instruction + visual feedback, control) on posture using pressure sensors in a chair to detect posture. The visual feedback group received feedback every hour, and both intervention groups showed increased good posture. However, the effect decreased over time. Finally, Kim et al. [2016] measured the work disturbance on forward head posture feedback in a pop-up window recorded with a 3D camera on the monitor. The pop-up window appeared in the lower right corner of the screen in the form of an illustrated turtle. Participants' head posture improved on average, and the pop-up window did not seem to disturb them (except for one participant).

Although auditory feedback is frequently used for notifications, it is still perceived as disturbing

Tuncer et al.[4] compared audio, visual and tactile feedback on a smart backrest for sitting posture guidance. The participants in their study stated that they perceived the audio feedback as annoying, disturbing and indiscreet. Mironcika et al. [2020] designed a posture awareness t-shirt (see Figure 3.4) that was inlaid with magnets on the back that would connect during specific postures and produce a "cracking" sound, representing the cracking of the spinal joints during some movements.

---

[3] https://www.researchgate.net/publication/355820303 *(Accessed on 10.04.2023)*

[4] https://www.researchgate.net/publication/355820303 *(Accessed on 10.04.2023)*

Figure 3.4: Snap-Snap T-Shirts magnets connect during certain postures to produce cracking sounds. They provide an alternative to speaker-generated sounds since they do not require electricity.

Visual and vibrotactile feedback may be disadvantageous by their missing discretion

Different feedback modalities have varying effectiveness in promoting good sitting posture. Vibrotactile feedback, as proposed by Zheng and Morrell [2010], has been shown to encourage a learning effect of posture, leading to sustained improvement even when the feedback was disabled without the user's knowledge. However, vibrotactile feedback is not without sound and is, therefore, not as discreet in a public office environment, similar to auditory feedback. Visual feedback, on the other hand, as studied by Ishimatsu and Ueoka [2015], Goossens et al. [2012], Duffy and Smeaton [2013] and Kim et al. [2016], may not be as effective in promoting good sitting posture, as it has reduced noticeability and may cause work disturbance.

Posture mimicking could benefit visual feedback

The study by Taieb-Maimon et al. [2012] suggests that it may be beneficial to incorporate posture mimicking in feedback. However, this approach may not be applicable for posture guidance aimed at improving dynamic sitting since the initial posture may not necessarily appear bad. Taieb-Maimon et al. [2012]'s study aimed to investigate the effect of a photo training method (showing participants photographs of their "bad" posture) for reducing musculoskeletal risk using the Rapid Upper Limb Assessment (RULA) before, during, and after a 6-week intervention. The results indicated that both methods (office training and photo training + office training) had effective short-term posture improvement, but only the photo training group showed sustained improvement. The feedback involved displaying a photo of correct posture and current posture on the computer screen once every 20 minutes.

3.4.1 Interruption

Interruptions should preferably occur between breakpoints of a task to reduce adverse effects on the user

According to multiple resources, humans can perform different tasks in parallel as long as the tasks do not utilize the same cognitive resource [Wickens et al., 2015]. Interruptions can disrupt the user's primary task, leading to frustration, decreased efficiency and performance, and users may forget their goal [Horvitz et al., 2001]. Adamczyk and Bailey [2004] suggest interrupting users between breakpoints of their primary task to avoid interruption overload, as different moments of interruption within task execution have different impacts on the user's emotional state. Interruptions during these points in time result in less annoyance, frustration, time pressure, mental effort and perceived disrespect to the user's primary task [Adamczyk and Bailey, 2004]. Interruptions during task execution, however, can lead to errors and frustration, especially when they occur at the wrong moment [Haller et al., 2011].

Interruption modalities might not play an essential role in disruption

Warnock et al. [2011] found no difference in disruption of the primary task depending on interruption modality (visual, auditory, tactile, olfactory). The minor differences that were present lay in the inherent nature of the feedback modality (e.g., olfactory feedback being slow).

Vibrotactile feedback is perceived as more disturbing than visual feedback

Haller et al. [2011] investigated the impact of various feedback modalities (graphical, physical, vibrotactile) on sitting posture guidance during tasks with varying cognitive load scenarios. Contrary to other studies, they did not interrupt users when they deviated from one "optimal" sitting posture, but when they were sitting statically for over five minutes. However, the authors decide that the feedback should initiate a training session for the user rather than a simple shift in position, which may be more disruptive and lead to the user's unwillingness to use such a system if they have to perform a training session every five minutes. They found that the type of task influenced whether the participants postponed their training session, and vibrotactile feedback was perceived as the most disturbing feedback type. The physical, ambient avatar was rated as least distracting, and the authors suggest that additional visual feedback would be accepted if it did not interfere with the working screen, which may present an opportunity of implementing a peripheral feedback display.

3.4.2 Peripheral Feedback as a Means to Realize Calm Technology

Calm technology reduces interruptions and utilizes ambient media to enable smooth task transitions

Calm technology refers to an aspect of Human-Computer Interaction (HCI) that seeks to mitigate the adverse effects of interruptions while maintaining the benefits of continuous connectivity. Calm devices are often integrated into furniture or decorations to minimize their obtrusiveness [Dahley et al., 1998]. Calm technology enables users to transition smoothly between primary and secondary tasks without interruption [Hong et al., 2015b]. One subgroup of calm technology is ambient media, which utilizes the affordances of the surrounding environment rather than relying solely on traditional input devices like keyboards and touchscreens [Gellersen et al., 1999].

The presence of an ambient display does not increase workload during an n-back task

Shelton et al. [2022] investigated methods for measuring cognitive load induced by ambient displays in a laboratory setting. Participants completed an n-back task (a task which involves recalling an image, sound, or similar stimulus that appeared n runs ago) to manipulate performance in both the presence and absence of an ambient display. The researchers found that the n-back task was an appropriate method for measuring cognitive load and that the presence of an ambient display did not induce additional workload, despite the peripheral information being perceived well by participants.

Costanza et al. [2006] have developed a wearable peripheral display consisting of blinking LEDs in glasses to provide notifications in public spaces discreetly. The authors emphasize the importance of such devices providing information without disrupting the user's immediate environment, particularly in mobile scenarios where users are preoccupied with their environment. This is also relevant in sitting posture guidance, where users are similarly preoccupied with their primary task. The visibility of the peripheral information was found to depend on the workload of the primary task and could be controlled through the brightness and velocity of the LEDs.

Visibility of peripheral information can be controlled through brightness and velocity

Costanza et al. [2006] advocate for a minimalistic design approach to peripheral feedback to avoid excessive disturbance to the user and to allow the user to decide whether to switch tasks based on their mental capacity. This differs from the artificial intelligence approach described by Adamczyk and Bailey [2004], in which their system makes assumptions about the user's current task and decides whether or not to interrupt the user.

Minimalistic peripheral feedback lets users decide when to switch tasks based on their own mental capacity

Peripheral displays play a significant role in providing information without interrupting the user's primary task, but static displays can be limited and uninteresting [Plaue and Stasko, 2007]. Plaue and Stasko [2007] investigated the impact of adding animation to a secondary display to enhance its appeal without making it too distracting. The study tested four configurations (secondary display next to the main display straight or angled, beamed to the wall behind the main display and on the TV behind the main display) of the display and found that the angled display showed the highest self-reported distraction. However, the other configurations do not appear practical for an office or coworking space. Disruptiveness was rated low, independent of the display configuration. However, in Plaue and Stasko [2007] participants had to remember information from the secondary display, which differs from the approach used in sitting posture guidance, where the user only has to react to the feedback. However, the authors demonstrated that it was possible to incorporate animation in a peripheral display without significantly distracting users from their primary task.

Disruptiveness of feedback can be reduced by using peripheral displays for information presentation

Continuous movement in peripheral feedback might distract from the primary task too much

Maglio and Campbell [2000] have studied the effects of peripheral information on disruption, finding that slight motion in a peripheral animation was not too distracting but that continuous motion should be avoided. However, their study only analyzed information of a scrolling or static nature, and it is unclear whether these findings are transferable to an animation that shows an ambient image compared to textual information. Additionally Mairena et al. [2019] report that continuous movement in the peripheral field of vision might be too distracting. However, they tested that in a study where the participants were playing a video game for the primary task. Since video games typically already involve a lot of motion and visual load, which differs from typical office work, this could be a factor that influences the outcome of their study in a way that can not be compared to the area of sitting posture feedback [Wang and Duff, 2016].

An anthropomorphic avatar, e.g., in form of a flower can be utilized for peripheral feedback

Hong et al. [2015b] created an ambient avatar in the shape of a flower (see Figure 3.5) to emulate the posture of the user, which is measured with two IMU sensors that are located on the user's back. The ambient avatar was based on previous work by Haller et al. [2011] but was enhanced with richer details mirroring the user's posture. The system incorporated a warning against static sitting for more than five minutes, prompting users to take a short walk. Frequent shifting of sitting position was evaluated as a sign of discomfort that should be improved through an exercise session.

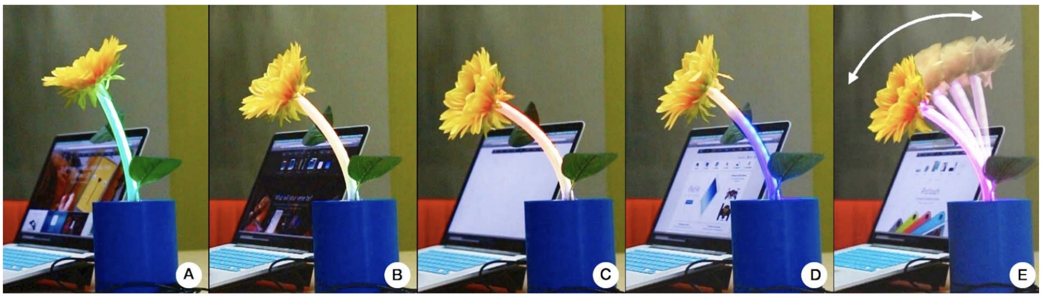

Figure 3.5: Flower-shaped ambient avatar by Hong et al. [2015b]. The avatar represents an example of anthropomorphic physical feedback, bending its stem to mimic the user's posture. Image from [Hong et al., 2015b].

The idea of a flower-shaped avatar was extended to a digital plant in an app prototype called BeuPo in Hong et al. [2015a]. The authors utilized a Point, Badge, Level (PBL) system to allow users to customize and cultivate their virtual plant avatar. The prototype employed a single IMU located on the user's back to measure posture. The PBL system was inspired by fitness applications such as *Fitbit*[5] and *Apple Fitness*[6], which incentivize users to improve their fitness by earning points, levels, and badges for completing challenges. In addition to the avatar's stem bending in response to the user's sitting posture, the prototype features a fostering system that allows the user to raise the plant from a seed to a fully-grown flower, fostering an existential relationship with the avatar. The user was prompted to perform actions such as cleaning their room or watering the plant when certain conditions were met, such as the appearance of a spider web or the plant becoming dry. The authors also included a garden system, similar to that of the Forest app[7], where fully-grown plants can be placed and viewed, along with posture statistics and the time it took to cultivate them. This allows users to track their progress.

Such an avatar can be supplemented by a PBL system and gamification to increase users motivation in improving their posture

Another application of an anthropomorphic flower for posture guidance can be found in Wölfel [2017]. The author

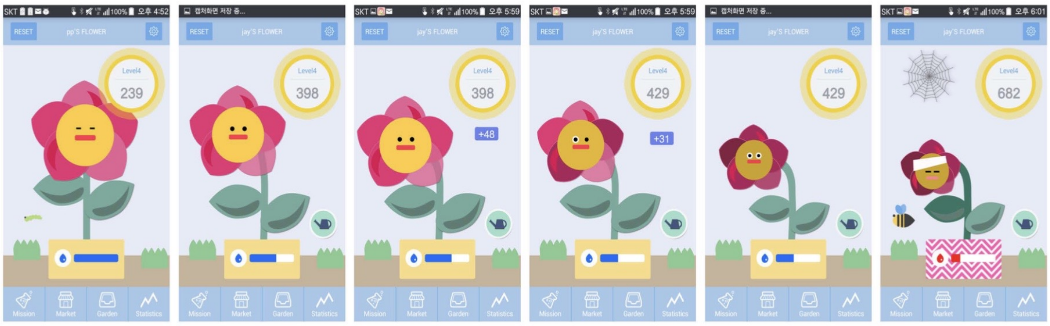

Figure 3.6: The anthropomorphic digital avatar BeuPo imitates the user's posture, measured with a single IMU on the upper back. It arouses attachment from the user with the anthropomorphic conveyance of emotions. Image from [Hong et al., 2015a]

---

[5] https://www.fitbit.com/global/de/home *(Accessed on 16.04.2023)*

[6] https://apps.apple.com/de/app/fitness/id1208224953 *(Acessed on 16.04.2023)*

[7] https://www.forestapp.cc *(Accessed on 10.04.2023)*

It is also possible to present an anthropomorphic flower digitally

has studied the perceived usefulness, ease of use and intention to use a digital anthropomorphic orchid for sitting posture guidance. They projected an image of an orchid on a wall next to the user's computer; in peripheral vision. Sitting posture was measured with the *Microsoft Kinect* camera. The user had to research any topic in Wikipedia and monitor the orchid feedback. Questionnaire results show that the users find the system useful and easy to use but would probably not use it on a daily basis. They do not go into further detail as to what justified this position. However, we assume that the reason might lie in the complex setup of the feedback, which would require a projector positioned behind the user and an empty, white wall in front of the computer. Wölfel [2017] has not evaluated quantifiable performance.

Utilizing digital pets is another way of incorporating anthropomorphism and an emotional connection to the user

Anthropomorphic flowers do not pose the only approach to creating an emotional connection with the user. Min et al. [2015]'s Pretty Pelvis is a smartphone application that connects to a sensor-equipped seat for sitting posture guidance. The smartphone incorporates virtual pet interactions to break sedentary behaviour. The interactions include a nurturing system where the pet's health depends on the user's sitting posture (e.g., when the user is putting more weight on the right side of the body). Khurana et al. [2014]

Figure 3.7: The peripheral setup of the anthropomorphic orchid as sitting posture feedback demonstrates a graphical alternative to ambient avatars. Image from [Wölfel, 2017].

uses vibration in combination with a graphical representation of a giraffe “NeckGraffe” for feedback and to represent the current neck posture of the user, resembling the animation in PosturePal[8]

There is a lack of user studies conducted on posture feedback for most anthropomorphic prototypes

Although some prototypes exist for sitting posture guidance with the help of anthropomorphic objects (plant or animal), only Haller et al. [2011] have formally evaluated their prototype in a user study. However, their user study initiated users to do an exercise session every five minutes of static sitting, which is not practical in an office environment due to the primary task’s eventual cognitive and temporal pressure.

An ambient display is superior in terms of user acceptance measures and visibility in comparison to a central display and no display

Lee et al. [2020] aimed to evaluate the effectiveness of an ambient display for real-time posture feedback compared to an on-screen display and a no-display condition in terms of dual-task performance of sitting posture monitoring and computer work. The authors measured detection efficiency, user acceptance measures, the number of typed answers and the occurrence rate of high-risk postures (measured through a pressure sensor chair). The results showed that ambient and on-screen displays enhanced dual-task performance compared to the no-display condition. The ambient display was superior to the on-screen display regarding subjective experience measures, visibility, and understandability. However, Lee et al. [2020] used two different images for displaying posture in the periphery (ambient sun, half hidden behind a cloud, blinking for feedback) and central field of vision (stick figure that changes colour from black to red and posture from straight to slumped during feedback), which may have influenced the results. The authors categorized eleven ergonomically relevant posture types (see Section 3.2) into low-risk and high-risk postures, which would trigger the feedback. They found that posture feedback significantly benefits the dual-task performance. However, the users criticized the insufficient salience of the ambient display, and the authors suggest that ambient feedback for sitting posture guidance should be provided more pronounced and noticeable.

---

[8] https://apps.apple.com/de/app/posture-pal-improve-alert/id1590316152 *(Accessed on 10.04.2023)*

Motion increases noticeability of peripheral information

Furthermore, Bartram et al. [2003] conducted a user study and developed guidelines for motion-based techniques in peripheral displays. They found that (slow) motion was more effective in getting user's attention than shape or colour changes, even during highly engaging primary tasks. Peripheral photoreceptors are more sensitive to movement than colour compared to central photoreceptors (see Section 2.3.1). Faster movements reduced the response time of participants. Among different motion types, travelling motions (where the subject was changing location on the screen) and zooming motions (where the subject changes size along the depth axis of the display) were perceived as more distracting than anchored and linear motions.

Chapter 4

Implementation

This chapter presents the development and implementation of our feedback system, along with our underlying design considerations. We begin by introducing the script for simulating a primary task. Following that, we describe the feedback representation animations and their mechanisms. We then explain how our system triggers a feedback transition of the animation. Finally, we present our definition of posture classes and maximum holding times, as well as how we incorporated the measurement and analysis of the corresponding joint angles.

4.1 Primary Task

We created a GUI for each primary task, where the user can input a letter that is shown on the screen

We created two *Python*[1] scripts for the primary task that incorporate the *tkinter*[2] package to develop a graphical user interface (GUI). The GUI consists of a randomly generated uppercase alphabet letter, a text input field, and a confirmation button (see Figure 4.1). We save the displayed letter, user input, and the corresponding timestamps (using the computer's system time) in a `dataframe` for further analysis. To measure the performance of two different cognitive

---

[1] https://www.python.org *(Accessed on 10.04.2023)*

[2] https://docs.python.org/3/library/tkinter.html *(Accessed on 10.04.2023)*

load tasks (as described in Section 5.4.1), we designed two scripts, namely `testGame` and `testGameHard`. We configured the `testGame` script to require the user to input the letter displayed on the screen, while the `testGameHard` script requires the user to input a letter that was presented two letters earlier. We save a boolean value indicating whether the input was correct in the dataframe mentioned above. The GUI of `testGameHard` presents an inactive input box for the first two iterations to prevent letters from being entered until two repetitions have been completed.

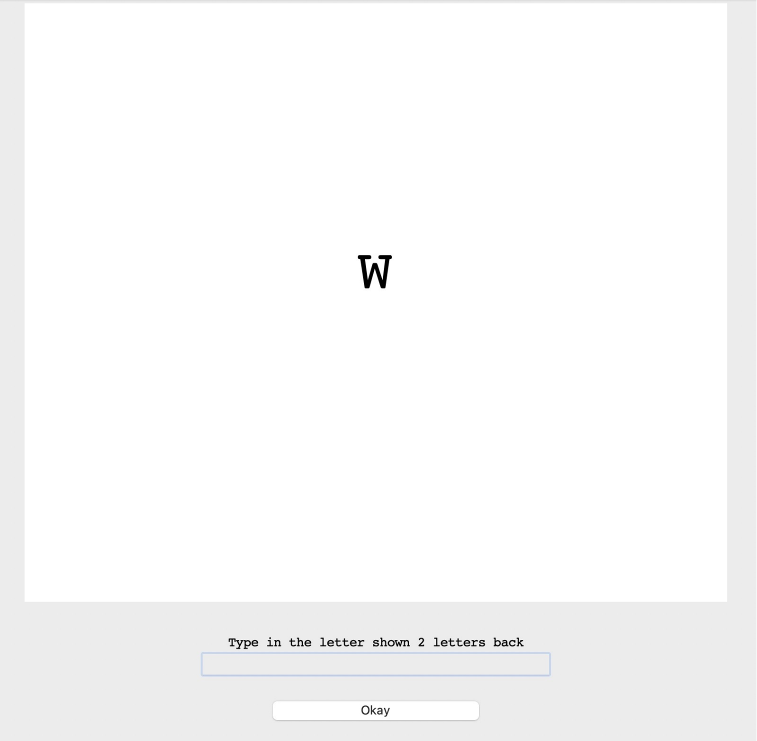

Figure 4.1: The interface of `testGameHard` displays an inactive input box for the first two iterations to prevent letters from being entered when two repetitions have not yet been completed.

4.2 Secondary Task

4.2.1 Peripheral Display Animations

We created three different animations for the peripheral feedback display

Based on the results of the preliminary study (see Section 5.1), we decided to create three different subjects for the animations displayed on the peripheral screen. We asked users in question eight to rank various peripheral displays. The results showed that we could roughly divide the respondents into two categories: Those favouring anthropomorphic representations that can establish an emotional connection with the user and those who favoured an abstraction of the spine that soberly represents the current state of the spine. There were also some proponents of more abstract representations, but they tended to be less well-received overall. From these findings, we defined three representation classes:

Anthropomorphic Representation:

The anthropomorphic representation in the shape of a tree loses its leaves and gets sad during feedback

We created an anthropomorphic representation by assigning a face (eyes and mouth) to a tree model and linking it to emotions, that reflect the state of the sitting posture. To represent a good sitting posture, we designed large and voluminous branches in green colours, lively leaves reaching towards the sky and a happy, relaxed facial expression. In contrast, we represented the feedback that stimulates a change in sitting posture by designing leaves that turn brown and slowly fly to the ground, a balding, smaller treetop, branches that sag a bit and no longer reach straight to the sky, and a despairing, sad facial expression.

Abstraction of the Spine:

The abstraction of the spine displays a severe kyphosis during feedback

We represented an abstraction of the spine by simplifying the structure of the vertebral bodies in the sagittal plane. A resting state, or positive sitting posture, is displayed as a spinal representation that reflects the neutral S-shape of the spine in an upright stance. To provide feedback for changing position, we modified the shape of the spine. Since the thoracic spine's kyphosis and the lumbar spine's lordosis are considered optimal [O'Sullivan et al., 2012], we display the lumbar spine in a less intense lordosis and the thoracic spine in an extreme kyphosis to reflect the frequent "slouching" sitting position. However, this does not necessarily represent the worst sitting position but may still be perceived negatively by users.

Abstract Representation:

The abstract representation resembles a lava lamp

We incorporated an abstract representation of sitting posture status into our design by creating an animation that features moving bubbles similar to a lava lamp. Our choice of this representation was based on the goal of creating an aesthetically pleasing and discreet variant that would not be immediately associated with sitting posture. In this representation, good posture is represented by green bubbles that float slowly around the display. Feedback is indicated by increased bubble velocity and a change in colour to red.

Green colours were used for idle and red colours for feedback states

We chose colours of lower saturation to create a calming effect, as suggested by several participants from our preliminary study, particularly for the resting state.

We created the base images for the animations in Procreate and converted them to vector graphics

We used the iPadOS application *Procreate*[3] (Version 5.2) to draw the base of the animation. However, since Procreate only allows for the exportation of bitmap graphics in portable network graphics (PNG) format, we had to convert them to scalable vector graphics (SVG) files. Since the spine representation had only one layer design with non-overlapping vertebrae as the elements of the abstract representation, we could convert the entire image. However, before conversion, the tree representation had to be split into individual layers (Main Stem, Secondary Stem, Back Crown, Middle Crown, Front Crown, Happy Face, Sad Face, Leaf 1, and Leaf 2). We converted the PNG files using the website *pngtosvg*[4]. Afterwards we imported the SVG files into a *Rive*[5] project for animation. The final animations were composed of four partial animations:

The idle animation has a green colour scheme and moves slightly

Idle Animation: The *anthropomorphic representation* wriggles slightly from left to right, reminiscent of swaying softly

---

[3] https://procreate.com *(Accessed on 10.04.2023)*
[4] https://www.pngtosvg.com *(Accessed on 10.04.2023)*
[5] https://rive.app *(Accessed on 10.04.2023)*

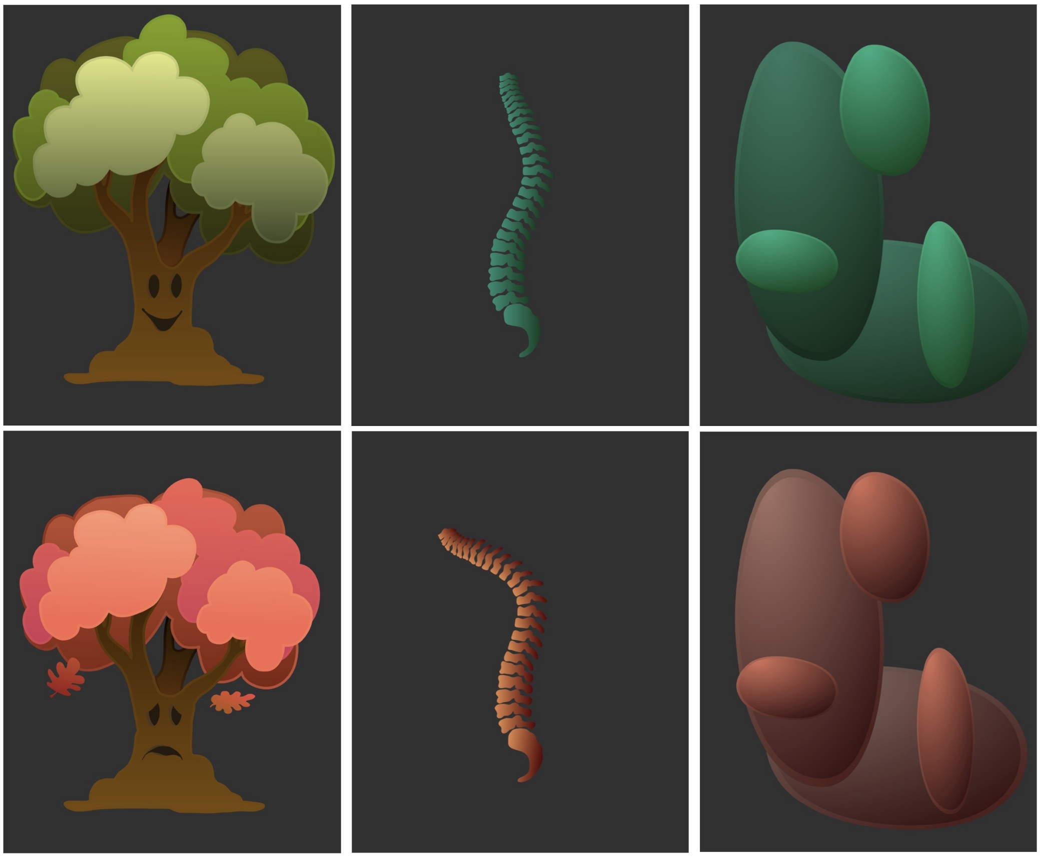

Figure 4.2: The appearance of the animations during the idle state can be seen in the upper images. From left to right *anthropomorpic representation*, *abstraction of the spine*, *abstract representation*. When the user needs to shift their posture, the animations change to the feedback state, depicted in the lower row.

in the wind. The *abstraction of the spine* makes an expanding and contracting motion reminiscent of breathing. The bubbles in the *abstract representation* move slowly from the bottom of the screen to the top, changing shape as they do so. All animation objects are portrayed in predominantly green tones during the idle animation.

Transition from Idle Animation to Feedback Animation: The *abstraction of the spine* bends forward, showing as a contraction to the left side of the screen. This is meant to be reminiscent of an exaggerated, forward-curved sitting posture. As the spine does so, the colour scheme changes from green tones to red-orange tones. The crown of the *an-*

When transitioning from idle to feedback state the animation changes colours from green to red *thropomorphic representation* shrinks, and the branches bend slightly. At the same time, the happy face of the tree changes to a sad expression. The colour scheme of the crown changes from a greenish tone to orange-pink tones, which should reflect the colour change of the leaves in autumn, symbolizing the change of the season of life, warmth and sunshine to the cold season, darkness and death. The bubbles of the *abstract representation* change colour from a greenish gradient to a reddish gradient.

The feedback state has a red colour scheme and incorporates faster movement to grab the user's attention

Feedback Animation: The *abstraction of the spine* retains the red-orange tint and pans from left to right, which is meant to represent panning anteroposterior to address the motion registration of peripheral vision. The *anthropomorphic representation* shakes by pivoting left and right rapidly. After shaking, two leaflets in red-orange tones fall from the tree crown to the roots and disappear before the tree shakes again. The bubbles of the *abstract representation* speed up but otherwise move the same to the idle animation with the difference that the colour is now reddish.

When transitioning from feedback to idle state the animation changes colours from red to green

Transition from Feedback Animation to Idle Animation: Here the opposite animation to the change from the idle animation to the final feedback is performed: The *abstraction of the spine* straightens back to the center of the screen, and the colour scheme changes from reddish to greenish. The *anthropomorphic representations* crown grows, changes colour scheme from reddish to greenish, the face changes from a despairing expression to a happy expression, and the branches stretch straighter toward the top. The bubbles in the *abstract representation* change from red to greenish.

The looping nature of the abstract representation made it necessary to make further adjustments to the animation

In the *abstract representation*, in addition to the transitions, we added one animation per direction for the fading and slow reappearance of the bubbles, which ensures that the animation elements are not visible on the screen for a short time during the transition phase. This has the background of inconsistencies in the transitions from one animation to the next due to the ″looping″ nature of the animation, where bubbles disappear at the top of the screen and slide back in at the bottom. This behaviour is not supported by the *RiveApp* and thus had to be worked around by giving the bubbles time to ″reset″ between transitions. The inconsistencies occur because the idle and the feedback animation are two different building blocks animated similarly. However, when changing, the end point of one animation does not correspond to the start point of the other. This would cause the elements of the animation to move from the stopping point of the first animation to the starting point of the following animation, resulting in an inconsistent appearance that could cause confusion for the user.

An animation state machine was created using the Rive animation editor to combine the single parts of each animation

We combined the animation parts into a state machine (see Figure 4.3) using the Rive animation editor. Initially, each animation starts in an idle state. We created a boolean variable called `badPosture` to enable the posture shift. The value of `badPosture` changes depending on whether the user's posture needs to be corrected. When `badPosture` changes to `True`, the state of the animation changes from idle to feedback, and the animation runs one repetition of the transition. The animation stays in the feedback state until the user corrects their posture, and `badPosture` changes to `False`.

An additional version of the anthropomorphic animation was created without continuous motion

We created an additional version of the anthropomorphic representation by omitting the movement during the idle (slightly bending in the wind) and feedback (shaking and loosing leaves) states to further test the effect of motion in our user study (see Section 5.4.2). This resulted in an animation that only incorporates movement in the transition states between idle and feedback.

Embedding of the Animations into a React Project

The final animations can be presented in a browser application

The animations can be exported from the RiveApp in their native file format. Rive officially supports a connection to *React*[6]. Therefore, we created a React frontend application by running each animation in the browser and saving the necessary files into the source folder: A Rive and a *JavaScript* file for each of the animations and a *JavaScript* file to manage the current output of the web browser, displaying the respective animation under `localhost/3000`. For easier readability, the names of the animations were abbre-

---

[6] https://react.dev *(Accessed on 10.04.2023)*

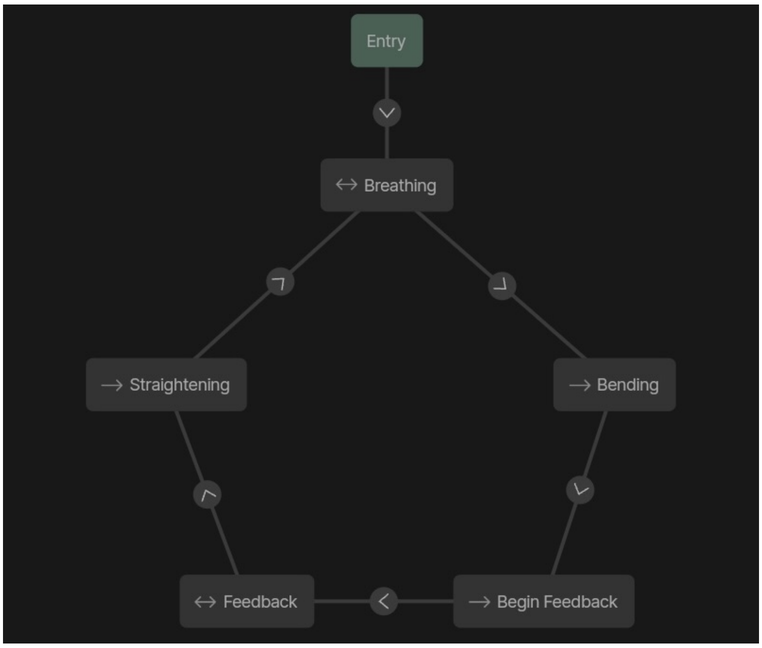

Figure 4.3: The state machine of the *abstraction of the spine* animation in the RiveApp. The animation begins in the idle state *Breathing*. When feedback gets triggered, it transitions to *Bending*, and after it has finished one run, it changes to *Begin Feedback* and afterwards *Feedback*. If the feedback trigger gets inactive, the state changes to *Straightening* and, after one run, returns to *Breathing*.

viated to *abstraction* for the *abstract representation*, *tree* for the *anthropomorphic representation* and *spine* for the *abstraction of the spine*. Each animation is rendered in its React component and can be accessed on the main screen. The animation is aligned to the maximum size of the screen. Any borders and missing areas that occur due to the dimensions of the image are filled with the colour of the animation background (*#313131*).

Feedback data was sent to a port by the backend and simultaneously read by the frontend application

To intercept files from the *Flask*[7] backend that processes the user's real-time posture data, we utilized the React functions `useState` and `useEffect`. Within the `useEffect` function, we set the `eventSource` to

---

[7] https://flask.palletsprojects.com/en/2.2.x/ *(Accessed on 10.04.2023)*

`localhost:5001/stream`, which is the location where our real-time posture data arrives. The `handleStream` function compares the data from the backend stream and modifies the state of the state machine to either false or true accordingly. This causes a state change in the state machine if a feedback event occurs, and the state machine transitions to the feedback mode. When the user changes their position, the state machine shifts into idle mode. In the event of an error, the stream is terminated.

Connecting the React Project with the Python Backend

To modify the animation, we transmit an impulse from the user interface to the React frontend using server sent events (SSE) facilitated by the Flask backend. The Flask backend sends the data to `localhost/5001` instead of the default port 5000, reserved for AirPlay on a Mac. This port allocation issue only affects Macs and should not arise on Windows machines. We retrieve the data via a proxy that accesses port 5001. To enable this functionality, we create an event that continuously retrieves the data over the SSE connection and triggers an action upon detecting a modification or addition. Next, we access the Rive file and adjust the `badPosture` value specification based on the input received from the backend, setting it to either `True` or `False`. The animation changes accordingly through state transition in the state machine. A schematic representation can be seen in Figure 4.4.

We modify the animation by adjusting the bad posture value in the Rive file, using an SSE connection to transmit data from the Python backend to the React frontend, and retrieving the data via proxy.

4.2.2 Real-Time Communication with the Xsens MTw Awinda System

MVN Analyze cannot support real-time streaming data with Python. As a result, we developed a customized Python script to acquire user datagram protocol (UDP) data, based on the decoding procedure described in the MVN real-time network Streaming Protocol Specification

We receive the real-time sensor data per UDP connection

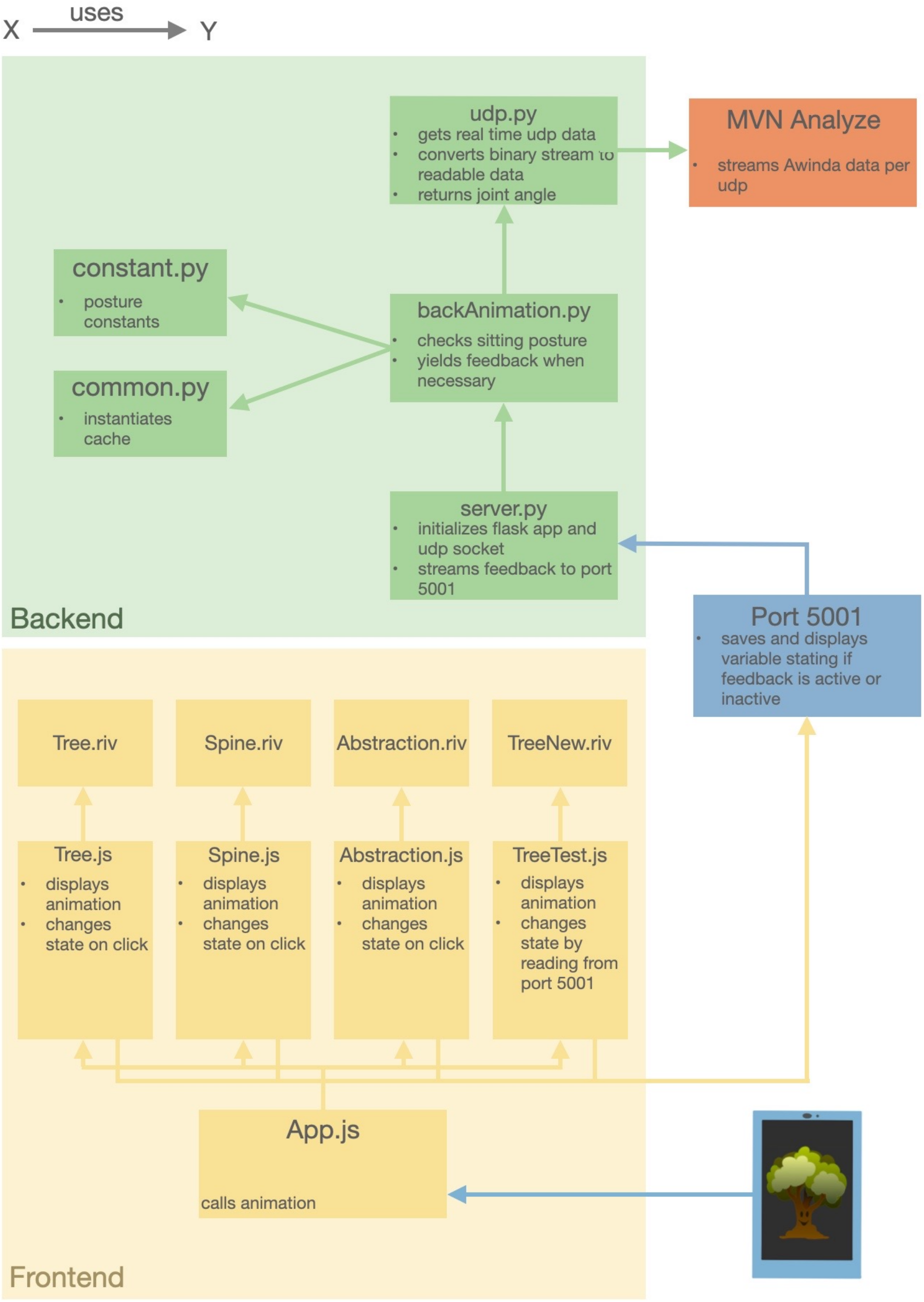

Figure 4.4: The diagram depicts the functionality of the feedback implementation. The backend takes real-time data from *MVN Analyze* and processes it to send a feedback signal to port 5001. The Javascript files in the frontend read the information from port 5001 and change the animation when a feedback signal arrives.

(NSPS)[8] and the existing script for the *MATLAB*[9] connection in the Software Development Kit (SDK)[10]. We implemented the UDP packet reception and processing in the Python method `udp()` within the `udp.py` script. We bound a web socket to port 9736, which Xsens utilize to supply real-time data. In a while loop, we intercepted the UDP message and decoded it into `messageID`, `messageType`, `sampleCounter`, `datagramCounter`, `numJoints` and `timeCode`. The interpretation of this data can be found in the NSPS. Subsequently, we transformed the remaining message from a byte stream to Euler angles. We identified the joint angles' respective ID (see Table 4.2) from the NSPS and decoded the joint information at the appropriate location in the message.

It is important to note that the spine segments in MVN are not measured directly but interpolated between the pelvis, sternum and head data. A spine model is used for this purpose.

Awindas spine angles are not directly measured but interpolated from other joints

4.3 Posture Estimation

4.3.1 Definition of Sitting Postures and Holding Times

In order to get a better overview of the effect of various sitting postures on the joint angles of the Xsens system, we measured one male and one female test person for trial. We asked them to recreate the typical ten office sitting postures from [Tan et al., 2001] and the reference postures from O'Sullivan et al. [2012] while wearing the MTw Awinda system.

We measured joint angles of the Awinda system on male and female test subjects replicating reference sitting postures

---

[8] https://www.xsens.com/hubfs/Downloads/Manuals/MVN_real-time_network_streaming_protocol_specification.pdf *(Accessed on 10.04.2023)*

[9] https://matlab.mathworks.com *(Accessed on 10.04.2023)*

[10] https://www.movella.com/support/software-documentation *(Accessed on 10.04.2023)*

[11] https://www.xsens.com/hubfs/Downloads/usermanual/MVN_User_Manual.pdf *(Accessed on 10.04.2023)*

Number	Joint Label	Corresponding Joint Definition
1	jL5S1	Joint between the lumbar spine segment 5 and sacral spine 1
2	jL4L3	Joint between the lumbar spine segment 4 and lumbar spine segment 3
3	jL1T12	Joint between the lumbar spine segment 1 and thoracic spine segment 12
4	jT9T8	Joint between the thoracic spine segment 9 and thoracic spine segment 8*
5	jT1C7	Joint between the thoracic spine segment 1 and cervical spine segment 7*
6	jC1Head	Joint between the cervical spine segment 1 and the head segment

Table 4.1: Joint IDs of the relevant joint angles and their definition. * The joint definitions are not mentioned in the MVN user manual but are theorized by us from the context of the remaining definitions. Source: Xsens MVN User Manual 01.04.2021[11].

Segment Name	Segment Index
Pelvis	0
L5	1
L3	2
T12	3
T8	4
Neck	5
Head	6

Table 4.2: The segment indices in the UDP data stream from the NSPS. We only included segments relevant to our posture classification. See Appendix A for the full data.

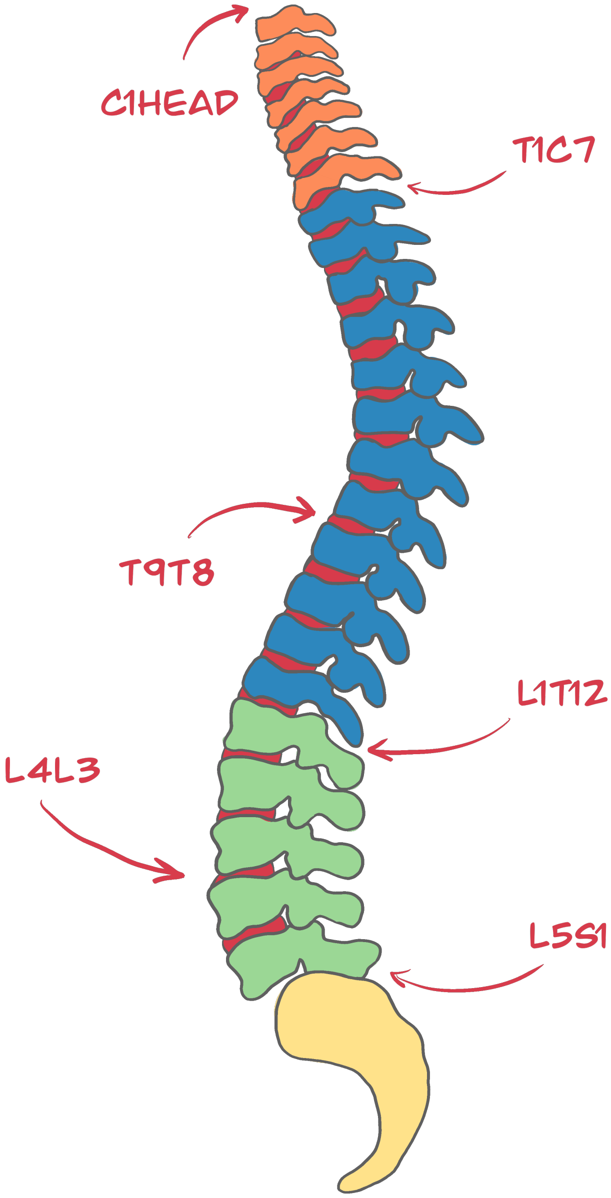

Figure 4.5: The Joints *C1Head*, *T1C7*, *T9T8*, *L1T12*, *L4L3*, *L5S1* that are approximated by the Awinda system and their location on the spine.

We defined posture categories, analyzed posture characteristics and set angle limits for the respective joints.

For the definition of our posture categories, we referenced O'Sullivan et al. [2012]'s assessment of high and low-risk postures. We defined three main risk classes for postures (*low-risk*, *medium-risk*, and *high-risk*) and assigned each of the nine postures from O'Sullivan et al. [2012] to one of the risk classes depending on the physiotherapists rating (see Table 4.3). Afterwards, we analyzed the postures more thoroughly. We defined their main characteristics regarding the thoracic and lumbar spine angles, which can also be found in Table 4.3 under *descriptions*. This resulted in five different postures that we could differentiate with the Awinda. We defined angle limits for the respective Awinda joints reflecting the description of each posture class (see Table 4.3). We used the data, gathered during the trial measurements to define the limits. For a better understanding of how the different posture categories might look like, we have presented a simplified visualization in Figure 4.6.

We decided to rely on joint angles L5S1 and T9T9 for posture estimation

Ultimately, we excluded the second high-risk posture (severe lordosis in the lumbar spine and severe kyphosis in the thoracic spine) due to its inability to be accurately reproduced with the Awinda system while sitting. Based on trial data analysis, we also evaluated sitting posture using Awinda angles L5S1 and T9T8 instead of L4L3 and L1T12, as these had a more significant impact on joint angles, as can be seen in Table 4.3.

Axial rotation acts as a risk factor for musculoskeletal disorders when rotations over 20° are held for prolonged periods

With O'Sullivan et al. [2012], we could classify various postures based on sagittal plane spinal angles. While prolonged trunk twisting in the transverse plane can contribute to low back pain and musculoskeletal disorders, Torén [2001] demonstrated that significant increases in trunk muscle activity only occur with more than 20° of twist and prolonged posture retention (several hours).

It was essential not to choose too small limits because slight deviations can even occur during straight posture

In selecting the limits for lateral bending and axial rotation, we considered angles beyond the maximum extension (upright position) and flexion (slouching position) of the spine to avoid false recognition due to slight deviations that can occur even during seemingly "straight" sitting without frontal or transverse plane rotation.

Posture	T1C7 [°]	L5S1 [°]	L4L3 [°]	T9T8 [°]	L1T12 [°]	MHT [min]	[O'Sullivan et al., 2012]	Lumbar Posture	Thoracic Posture
Lateral Bending	>5					1	-		
Axial Rotation	>5					1	-		
Low-Risk		5-10	-5-0	<9	<5	3	5,9	Slight lordosis	Slight kyphosis
Medium-Risk 1		>10	>0	5-9	1-5	2	4,8	No lordosis	Slight kyphosis
Medium-Risk 2		<5	<-5	<5	<1	2	2	Severe lordosis	Extension
High-Risk 1		>20	>0	>9	>5	1	1, 3, 6	Flexion	Flexion
High-Risk 2		<20	<5	>9	>5	1	7	Severe Lordosis	Severe Flexion

Table 4.3: We defined maximum and minimum limits for each posture class, resulting in seven classes. Each class corresponds to at least one of the reference postures in O'Sullivan et al. [2012]. We defined a maximum holding time (MHT) for each posture class based on Tahernejad et al. [2022].

For bending and rotation, we defined an angle limit of 5°

The C1Head joint exhibits the highest values of spinal flexion ranging from 10.4° to 17.9°, while the T1C7 joint ranges from 5° to 11° when leaning to the side. However, the parameters used to evaluate spinal flexion (L5S1, L4L3, T9T8, and L1T12) demonstrate minimal angular changes, making them inadequate for detecting lateral spinal flexion. As a result, we decided to define an angle of ± 5° in the T1C1 joint to observe bending postures since the neck/head compensates for most of the flexion and rotation, resulting in no significant changes in the other spine parameters. Given the lack of information on axial rotation risks of short duration, we used an angle of ± 5° in the T1C7 joint as the inclusion criteria for axial rotation positions.

We did not consider neck posture due to its complexity

The complexity of the neck exceeded the scope of this master's thesis; hence, we opted not to incorporate neck posture in this work.

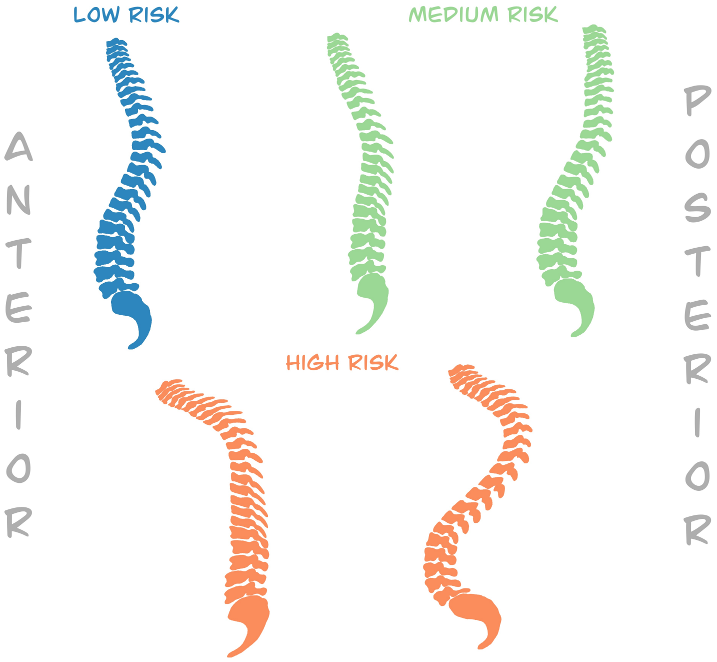

Figure 4.6: A schematic representation of the five defined posture categories in the sagittal plane. The visualization does not correspond to the anatomically correct spine posture but only serves as an aid for imagination.

In Tahernejad et al. [2022], the maximum recommended holding time for most postures lies between 1.5 and 3 min. The maximum holding time decreases depending on the strength of the deviation from the natural spinal shape. Since these are maximum values, we defined maximum holding times between one and three minutes depending on the risk class of the posture. The *low-risk posture* considered optimal in O'Sullivan et al. [2012] can be held the longest, with a maximum duration of three minutes before feedback occurs. The *medium-risk postures* may be held for a maximum of two minutes, and the *high-risk postures*, including greater *lateral bendings* and *axial rotations* a maximum duration of one minute. The defined maximum holding times are included in Table 4.3.

We define maximum holding times from one to three minutes depending on the posture risk class

4.3.2 Interpretation of Joint Angle Data

In the context of analyzing sitting posture, we analyze the real-time joint angles of L5S1, L1T12 in the x-direction and T1C7 in the y-, and z-direction for lateral bending and axial rotation using the function `analyzePosture()` in `backAnimation.py`. Based on the joint angles, we classify the current posture into one or more predefined postures, including lateral bending and axial rotation postures held simultaneously with one posture in the sagittal plane. Upon a posture change, we initialize a timer to count the duration of the user's time in the respective position using the function `feedbackTimer()`. When the maximum holding time is exceeded without a change in posture, the timer changes its state, prompting a feedback change from `analyzePosture()` that triggers the Flask server to return the respective value to `localhost/5001`. We have provided a schematic diagram of this process in Figure 4.4.

We interpret the sitting posture with a timer and initiate feedback when the user exceeds the maximum holding time of their posture

The GitLab repository Sitting Posture Guidance[12] contains the implementation files that were mentioned in this chapter.

---

[12] https://git.rwth-aachen.de/i10/thesis/thesis-julia-reim-sitting-posture-guidance *(Accessed on 10.04.2023)*

Chapter 5

User Study

5.1 Preliminary Study

To get a first insight into the topic, a preliminary interview was conducted with 11 participants (6w, 5m) who had an average daily sitting time of 7-8h. The average age of the participants was 26.27 years. Table 5.1 shows a breakdown of the participants' demographic data.

We conducted a preliminary study for first insights

	N	Age in Years	Height in cm	Hours of sitting/day
Total	11	26,27 ± 6,5	167,91 ± 12,27	7,18 ± 2,53
Female	6	27,17 ± 9,04	158,67 ± 6,12	7,33 ± 1,97
Male	5	25,2 ± 0,84	179 ± 6,89	7 ± 3,08

Table 5.1: Demographic data of the participants in the preliminary study.

The interview was a semi-structured interview consisting of 12 questions and took place between the 27th of June and the 1st of July 2022. The subjects were informed before the interview about the purpose, data protection and processing of personal data, risks, compensation, and the interview duration. They signed a consent form which can be found in Appendix B. The interview was conducted in person or via video chat and was set for 30 minutes. The participants were given the choice to conduct the interview in German or English. All 11 subjects chose to be inter-

In an interview, we talked with 11 participants viewed in German. The questions that were asked during the interview can be found in Appendix C.

Demographical data of each participant was collected

Afterwards, the participants were asked about their age, gender and body height. The answers to the first question are noted in Table 5.1. An overview of the results of the other questions is shown below.

5.1.1 Results

Most participants have tried to optimize their sitting posture before

Have you ever tried to optimize your sitting posture? Nine participants answered a definite yes, while two participants admitted to not ever trying to optimize their posture.

- **If yes, how did you go about it?** Most participants answered that they would try to change their posture during the day when they spontaneously remembered it. They would do this by keeping their back straight and adopting an upright sitting posture or changing their position. One person each reported adjusting the height of the desk, increasing the distance of the head from the screen, researching ergonomic sitting on the Internet or performing back exercises.

The participants thought about a straight and upright posture as ideal

How do you define a healthy sitting posture? All participants defined a healthy sitting posture as having a straight back, an upright posture, and no slouching forward. In addition, half of the participants considered a gaze directed straight ahead or slightly downward an essential component of a healthy sitting posture. In addition, several participants felt that the sitting posture should still be comfortable and not tense. The shoulders should be pushed back, the knees should not be crossed, there should be a sufficient distance to the screen, the chair back should be movable, and the feet should touch the floor. In addition, one person each mentioned that any movements should originate from the pelvis and not from the spine, that one should not sit crosswise on the chair, that the angles between the back, arms and legs should be 90° each and that an ergonomic sitting posture should be adopted. One person said that for this purpose, the chair should be soft. Another person believed that the chair should not be too soft.

Participants did not consider their sitting posture as optimal but did not change it because they forgot or it was too hard

Do you think you have a healthy sitting posture while working at a desk? Six Participants answered that they were not sitting in a healthy posture, while five participants were sometimes trying to sit in a healthy posture but could not stay there for the whole duration of sitting.

- **If not, what keeps you from having a healthy sitting posture?** Over half of the participants indicated that maintaining a healthy sitting posture would be too strenuous and uncomfortable. Half of the participants indicated that they were fully focused on the main task, so the additional monitoring of the sitting posture would distract them. Some participants indicated that sitting posture was a matter of habit and feeling unusual for them or that they forgot to pay attention to their posture. One participant each reported that the motivation for the main task, additional people present in the room, lack of time, a font that was too small, the furniture not being adapted to the body size, pain, and the unnatural sitting posture due to operating the mouse with one hand contributed to the sitting posture not being healthy. In addition, one person shared that no one would stop them from sitting the way they did, and another person complained about the quality of the chairs.

Real-time feedback, customizability and a summary of sitting posture performance were important for our participants

What feedback would you like to get from a smart, posture-supporting device? The feedback that participants preferred could be broken down into four broad categories:

a. Summary

b. Real-time Feedback

c. Customizability

d. Other

In category a., participants requested a summary at the end of the workday or sitting period. In this regard, several participants expressed a desire for a visualization of good versus bad posture throughout the day and information about the harmfulness or extent of an incorrect posture. One person each wanted more discreet errors that would be too distracting in real-time feedback in summary, a listing about the positions one sat in, long-term consequences of poor posture as motivation, the progression or improvement of posture over days/weeks/months, information about the duration of sitting, and positive feedback and praise. In addition, diagrams were preferred over plain text.

In category b., over 80% of the participants wanted real-time feedback. More than 60% wanted to receive praise or a reward for good sitting posture. Two people wanted feedback in natural language. In contrast, one person each wanted feedback only after rough errors, a push message, a visual representation, the inclusion of light or colour, and a comparison of the current status of the posture to the preferred posture.

In category c., one person each wanted the device to be adaptable to different people, for the level of detail and the amount of feedback to be customizable and for the possibility of integrating one's personal sayings or mottos.

In category d. preferences that could not be classified in the previous three categories were collected. This includes that 50% of the participants wanted vibration as feedback. Further, participants wished for specific and detailed feedback. A simple "You are sitting wrong" would not be enough. One person each wanted very subtle cues, improvement suggestions or guidance, back exercises, app-based functionality, chat with an AI, beeping as a feedback modality, a massage, a tap on the shoulder, feedback that focuses on individual weak spots, funny, quiet feedback, a reason why the current position is wrong, the angle of the spinal curve, feedback that stays in the background, and specific daily goals to achieve. One person wanted the chair to start measuring and giving feedback immediately, while another person preferred feedback to be given after sitting for 30 minutes.

Loud and obtrusive feedback was disliked

What feedback would you dislike receiving from a smart, posture-supporting device? Slightly less than half of the participants said they preferred feedback that is not obtrusive or too strong. The same applies to loud signals and unpleasant noises. In addition, some participants complained about feedback that is too strict, peremptory, rough or excessively critical. Beeping and vibration are perceived as unpleasant by 30% of the participants. One person each stated that push messages, summaries, long continuous text, electric shocks, positive feedback, wrong remarks, and feedback that must be searched for first do not meet their expectations of good feedback.

The participants preferred vibrotactile feedback

Sort the following feedback modalities starting from most liked to least liked: Visual feedback on the main display, visual feedback on the peripheral display, sound/audio feedback, vibration, warmth/heat. The most liked feedback modality was vibration, closely followed by the peripheral display. The visual feedback on the main display was ordered in the middle, and audio and warmth feedback shared the last place. A graph depicting the results can be seen in Figure 5.1.

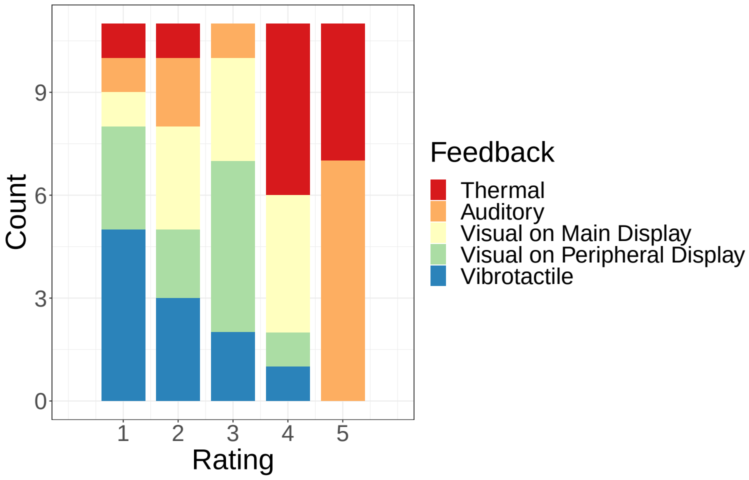

Figure 5.1: Ranking of the feedback modalities in the preliminary study. The participants preferred vibrotactile and visual feedback. Auditory and thermal feedback were not perceived positively.

Applied to a peripheral display, how would you rate the following visual representations of posture on a scale from 1 to 5?

a. Flower

b. Tree

c. Person

d. Animal

e. Minimalistic form

f. Abstraction of the spine

g. Abstract colours or brightness levels

There is no clear preference for feedback representation

The results of the interview question show no clear trend. One group of participants prefers emotionally binding representations like a flower, tree or animal, especially when those look cute. At the same time, the other group perceives those as childish and prefers the simple abstraction of the spine. A graph depicting the results can be seen in Figure 5.2

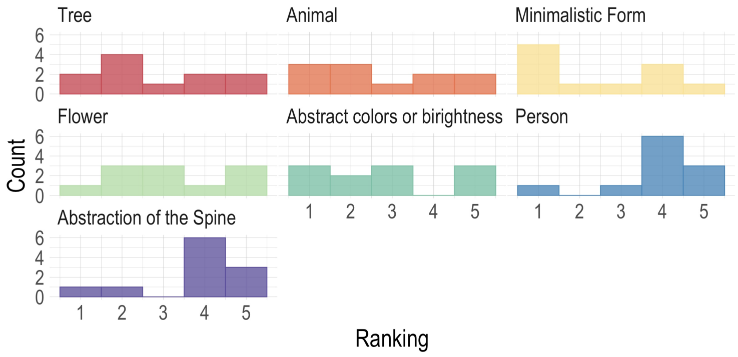

Figure 5.2: Ranking of the peripheral feedback representations. We did not find any clear trends in the ranking of different representations for the peripheral feedback.

Do you have any additional ideas or preferences regarding peripheral feedback? Half of the Participants stated the importance of an emotional bond to the representation. Some participants recommended including adjustable avatars like anime characters that motivate them, and some emphasized that they wanted the representation to look cute or funny. One participant preferred fewer distractions on the screen to focus on the important.

Most participants want to have an emotional bond to the feedback representation

Related to posture detection: Would you prefer to wear a measurement system on your body (e.g., smartwatch or headphones) or to have it integrated into the environment (e.g., chair with pressure sensors or camera)? Five Participants reported preferring the measurement system on the body, while six participants preferred it in the environment.

We did not find any preference between environmental and on-body measurement

Which characteristics should posture feedback meet to be useful for you?

a. It should not distract me from my main activity

b. It should be consistent with my aesthetic preferences

c. It should be discreet

d. It should be a feedback method that I already know

e. It should be customizable

All participants strongly agreed that the feedback should be adjustable. Most participants strongly agreed that it should not disturb them from their primary task. The characteristic of discretion ranged from neutral to very important, and the agreement with aesthetic preferences was necessary for some participants but not others. Compared to Tuncer et al.[1], most participants disagreed that it should be feedback they already are familiar with.

Participants value customizability and discretion

Are there any other features that would be important to you? Two participants suggested self-actuating furniture

It is essential to explain why a posture is good or bad

---

[1] https://www.researchgate.net/publication/355820303 *(Accessed on 10.04.2023)*

to guide them into a desired sitting position. Another participant wanted the posture monitoring system to be minimalistic and portable, like a blanket on a chair. Most participants stated that it was essential to know why their current posture was wrong, or another one would be better. One participant wished for feedback to be context sensitive, to not disturb during important work but to be more aggressive when they were only playing video games, for example. Another participant wanted additional feedback that would tell them when they looked at the screen for too long or needed to drink some water, similar to current smart watches' fitness and lifestyle applications.

5.1.2 Discussion

People care about sitting posture, want to improve it and do not consider their current posture optimal

As most participants have expressed their attempt to improve their sitting posture before, it can be inferred that sitting posture guidance is an important subject that people are concerned about. They acknowledge the issue with their posture or sitting habits and wish to address it. The results of our study, in which participants did not consider their sitting posture optimal, align with the findings of Korakakis et al. [2021].

Participants' perception of optimal sitting posture aligns with conventional ergonomic rules

When asked about optimal sitting posture, most participants envisioned a straight posture and conventional ergonomic rules such as those recommended by the Occupational Safety and Health Administration[2]. This notion is troublesome since recent studies suggest that dynamic sitting is the most beneficial sitting practice [Kastelic et al., 2018]. Static sitting, encouraged by a straight posture, can cause muscle tension and increased discomfort [Kastelic et al., 2018]. Participants may ignore signs of discomfort and exacerbate their condition if they believe that a straight posture is optimal, as they indicated that sitting straight for prolonged periods was taxing and uncomfortable. Following ergonomic guidelines may also be problematic because there is no scientifically validated solitary guideline [Kastelic et al., 2018].

---

[2] https://www.osha.gov/etools/computer-workstations *(Accessed on 10.04.2023)*

The fact that participants reported forgetting about their sitting posture during prolonged periods of sitting or lacking the mental capacity to attend to it supports the notion that non-invasive sitting posture feedback could benefit them.

Participants forgetting posture during sitting supports the need for posture feedback

Given that 80% of the participants expressed a desire for real-time posture feedback, it can be inferred that they would be willing to tolerate some level of interruption if it facilitates posture monitoring during their primary task. Additionally, participants expressed a desire for positive reinforcement, which aligns with a potential implementation of a PBL system as described by Hong et al. [2015a].

There is a need for real-time posture feedback and positive reinforcement

In terms of feedback modalities, it was found that vibration was the most popular among the study participants. However, discretion was also noted as an important consideration for participants. This creates a potential conflict as vibration can be disruptive and even annoying in specific settings, particularly in an office environment. Participants also expressed a desire for calibration, emphasizing the importance of customization in the feedback system. This could also extend to the customization of animations used in the system, as participants had varying preferences for feedback that was either anthropomorphic and connected to their emotions or straightforward and focused on providing information about their posture without incorporating an emotional component.

The participants preferred vibration, and they wished for customization of feedback and animations.

The variability in preferences for anthropomorphic vs. straightforward feedback highlights the importance of individual differences in designing an effective feedback system. The fact that participants requested calibration also underscores the need for a flexible system tailored to meet each user's unique needs and preferences. Such a system could allow users to modify the feedback based on their individual goals and preferences, ultimately enhancing the system's effectiveness in promoting better posture and reducing discomfort. Overall, these findings suggest that customization and flexibility should be key considerations when designing posture feedback systems to ensure that they are effective and well-received by users.

Customization, flexibility and calibration are important for effective posture feedback systems that can accommodate individual differences and meet users' needs and preferences

Auditory feedback was rated as less desirable

The study participants preferred non-intrusive feedback, which is a design goal for our prototype and can also be achieved through calm and ambient technology or peripheral feedback mechanisms [Hong et al., 2015b]. This aligns with the idea that audio feedback may be too disruptive [Exler et al., 2019], as indicated by participants rating auditory feedback lower on the scale.

Practicability seems to be the most crucial factor in the decision of a posture monitoring system

Given the lack of a clear trend among participants regarding their preference for on-body versus environmental posture monitoring systems, ease of use and practicality may be critical factors in their decision-making. Some participants expressed a desire for a portable and minimalistic system, which would not be well-suited for a complex and costly system such as the Awinda, which requires assistance to put on and may be impractical for everyday use.

We developed our three feedback prototypes based on the results of the preliminary interview

Participants considered sitting posture important and desired real-time feedback with a reward system and trend summary. These findings support using the Awinda for monitoring posture and proposing a real-time feedback prototype. Participant preferences for peripheral display animations led to the development of three prototypes to test their effectiveness.

5.2 Main User Study

We conducted a user study to explore peripheral sitting posture feedback

We conducted a user study to evaluate the effect of peripheral feedback for sitting posture guidance displayed on a screen and whether the effect of the feedback changes concerning tasks with different cognitive loads. We wanted to inspect the differences in the performance of the main task depending on three different display conditions: a peripheral display with continuous movement, a peripheral display without continuous movement and a condition without a feedback display. Furthermore, we compare three animation prototypes, each complying with a different user requirement, on their user experience.

Participants executed a dual task

The participants executed a dual task, consisting of a primary task in the central field of vision and a secondary task in the peripheral visual field. The primary task consisted of either a high- or low-load task, whereas the secondary task included paying attention to their sitting posture.

5.3 Aim of the User Study

We planned to evaluate our feedback system and check if there is a difference between mental loads and movement conditions in primary task performance

The controlled experiment aimed to determine the effectiveness of an anthropomorphic feedback display in guiding sitting posture and to assess whether there is a difference in the dual-task performance of sitting posture and the primary task under high or low mental load. Additionally, we aimed to determine whether there was a difference in dual-task performance between the animation with continuous movement and the animation without continuous movement.

We aimed to answer the following research questions:

RQ1: Does the error rate of the primary task differ between the three display conditions (peripheral display with continuous movement, peripheral display without continuous movement and no feedback)?

RQ2: Does the speed of the primary task differ between the three display conditions (peripheral display with continuous movement, peripheral display without continuous movement and no feedback)?

RQ3: Does the speed of posture change after feedback differ between the three display conditions (peripheral display with continuous movement, peripheral display without continuous movement and no feedback)?

RQ4: Does subjective workload differ between the three display conditions (peripheral display with continuous movement, peripheral display without continuous movement and no feedback)?

RQ5: Which animation prototype is preferred for sitting posture guidance?

According to Mairena et al. [2019], continuous movement in peripheral feedback may be more distracting than feedback without continuous movement. However, the primary task in their study consisted of playing a video game that already included some movement. We wanted to research whether continuous movement is as distracting during a primary task that has a more static nature. Costanza et al. [2006] show that peripheral feedback is less invasive than no feedback because users can switch seamlessly between the central and peripheral tasks. We expect our research to confirm this statement and reinforce the use of peripheral feedback for sitting posture guidance before using conventional feedback modalities. To answer our predefined research questions, we defined the following research hypotheses corresponding with RQ1 to RQ5:

We found evidence that continuous movement is distracting but want to test that in a sitting posture guidance setup

RH1: The error rate is higher during the continuous-movement condition than the no-movement condition, in line with Mairena et al. [2019]'s findings.

RH2: The speed of the primary task is lower during the continuous-movement condition compared to the no-movement condition, in line with Mairena et al. [2019]'s findings.

RH3: The duration until a posture change occurs after feedback is longer in the no-feedback condition than in the feedback conditions.

RH4: There is no significant difference in error rates between the conditions with and without feedback.

RH5: There is no significant difference in the speed of the primary task between the conditions with and without feedback.

RH6: The duration until a posture change occurs after feedback is higher during high-cognitive-load conditions than low-load conditions, based on Williams [1995]'s and Stokes et al. [1990]'s theory on tunnel vision.

RH7: The animation without continuous movement will perform better in subjective workload measures than the animation with continuous movement, in line with Mairena et al. [2019]'s findings.

RH8: The feedback conditions perform better in subjective workload measures than those without feedback.

We expect the research hypotheses to be supported by evidence gained from the user study. The hypotheses were based on prior research presented in Section 3.

5.4 Independent Variables

Task difficulty, feedback condition, and animation prototype are independent variables in the user study

The six test conditions of the main experiment result from a combination of two independent variables: The feedback condition, consisting of three levels (feedback animation with continuous movement, feedback animation without continuous movement and no feedback), and the difficulty of the primary task (low cognitive load, high cognitive load). The secondary experiment incorporates the three animation prototypes as an independent variable.

The conditions Movement, Low Load (ML); Movement, High Load (MH); No Movement, Low Load (NML); No Movement, High Load (NMH); No Feedback, Low Load (NFL) and No Feeback, High Load (NFH) that result from the combination of tasks are depicted in Table 5.2. The abbreviations will be used throughout the further work to refer to each independent variable.

Feedback	Task with **low** cognitive load	Task with **high** cognitive load
Animation **with continuous movement**	ML	MH
Animation **without continuous movement**	NML	NMH
No feedback	NFL	NFH

Table 5.2: Experiment independent variables.

5.4.1 Cognitive Load

Cognitive load is divided into the levels: low and high cognitive load

According to Wang and Duff [2016], more cognitive load leads to the desired tunnel effect where peripheral information will be registered less. However, there is a confounding factor in which more visual information leads to an overload of visual capacity and thus also to a tunnelling effect [Wang and Duff, 2016]. To mitigate the effects of this confounding factor, we decided only to show one letter in the center of the screen that would change into another letter that does not shift size or location for both task difficulties. We then introduced difficulty by incorporating a modified 2-back task instead of presenting additional information to enhance cognitive load, as seen in Savage et al. [2019]. We tested different variations of n for the modified n-back task and decided that a 2-back task had the right difficulty level for our purpose. In a pilot study, this assumption was validated by the participant. (Modified) n-back tasks have been widely used in various scenarios where participants should be subjected to different levels of cognitive load, e.g., [Hermand et al., 2019, Kesedžić et al., 2020, Novak et al., 2017, Savage et al., 2019] and Shelton et al. [2022] found that an n-back task is an appropriate method for measuring cognitive load in the area of peripheral information. The assignment that was given to the participant was as follows:

Task with low cognitive load:
Complete a **low** cognitive load task by entering a letter presented on the main screen into an input box and clicking a confirmation button.

Task with high cognitive load:
Complete a **high** cognitive load task by performing a modified 2-back task (entering the letter presented on screen two letters back) on the main screen. Enter the result into an input box and confirm by clicking the confirmation button.

5.4.2 Feedback

Three feedback conditions: animation with and without movement and no feedback

We decided to incorporate three different feedback conditions into the study. Since the advantages of peripheral feedback compared to central feedback have already been established in previous studies generally [Williams, 1995, Stokes et al., 1990] and particularly regarding sitting posture guidance [Lee et al., 2020], we only set up a condition without feedback as a reference to the feedback conditions.

The peripheral animations were designed to be aesthetically pleasing

Another reason for this decision is that we did not believe it was possible to include feedback in the main display that could be objectively compared to the peripheral animation. Such a design would need to be changed in size or form like in Lee et al. [2020]. We decided to use a peripheral animation and not just, e.g., a blinking light because we wanted to speak to the user aesthetically and because such animations were regarded positively in the preliminary study (see Section 5.1). We conducted the user study with the anthropomorphic representation, due to its popularity within our preliminary study results. Additionally, we have already seen similar prototypes [Haller et al., 2011, Hong et al., 2015b,a, Wölfel, 2017] that have not been validated in any user study yet.

We want to find out if there is a difference in dual-task performance based on the motion of the feedback

We included an animation with continuous movement and an animation without continuous movement because there is no explicit agreement in the scientific literature about the disruptiveness of motion in the periphery. While some authors speak for a continuous motion to increase noticeability and aesthetic perception [Parkes et al., 2008, Birnholtz et al., 2010, Bartram et al., 2003], other authors criticize the increased interruption from the primary task when continuous motion is presented in peripheral information [Maglio and Campbell, 2000, Mairena et al., 2019]. Since the difference between continuous motion and the absence of it was not analyzed for sitting posture guidance in peripheral displays yet, we decided to include this as an independent variable to compare interruption in the primary task.

Animation with continuous movement:
Monitor the peripheral feedback display with **continuous** movement and adjust your sitting position when feedback is displayed.

Animation without continuous movement:
Monitor the peripheral feedback display **without continuous** movement and adjust your sitting position when feedback is displayed.

No Feedback:
Practice dynamic sitting **without feedback** and change your sitting posture every 10-30 seconds.

5.4.3 Animation Prototype

We designed tree, spine and abstract animations

We designed three different animation prototypes (see Section 4.2.1): *Anthropomorphic representation*, *abstraction of the spine* and *abstract representation* in accordance with the findings of our preliminary user study (see Section 5.1). For the sake of readability, we will use *tree* to refer to the anthropomorphic representation, *abstraction* for the abstract representation, and *spine* for the abstraction of the spine.

5.5 Experimental Design

The experiment design was within-subjects with conditions balanced by Latin Square

The combination of the two factors, difficulty and feedback, did result in a 3 *feedback designs* x 2 *difficulties* + 3 *animation prototypes* study design. We conducted the experiment in a within-subjects design, where each participant interacted with each combination of conditions, leading to nine trials per participant. To counteract sequencing effects, the conditions *feedback designs* x *difficulties* and the condition *animation prototypes* were separately ordered by a Balanced Latin Square design.

Each study session took 90 to 120 minutes and was conducted in a laboratory setting

This resulted in 90 to 120 minutes per study session. The study was conducted in a laboratory setting of the RWTH-University Hospital.

5.6 Participants

We recruited participants with no history of spinal injuries or surgeries

Between the 23rd of January, 2023 and the 16th of February, 2023, we recruited N = 25 participants (13f/12m), aged 24.6 ± 3.32 years. The mean height of the participants is 173 ± 10.19 cm. One of the n participants was left-handed, while the other 24 used their right hand to operate the computer mouse. We have defined the participation requirements, that no acute or chronic spine diseases should be present and that there should have been no previous spinal surgeries. None of the participants have reported any previous spinal surgeries, while three announced to probably have mild scoliosis that does not negatively impact their sitting habits. We decided to keep those participants because they assured to not suffer any harm from sitting during the study. Some data tables got corrupted during the saving process, resulting in missing data from the primary task data (error rate and time to type in result). The amount of data available per data collection method is depicted in table 5.3.

Most participants had a predominantly sedentary lifestyle

Most participants (20) in the selected sample reported sitting for more than six hours a day on average, while four participants spent between four and six hours sedentary. Only one participant was sitting for less than three hours a day.

	Total Participants	NASA-TLX	Sensor Data	Task Data	Attrak-Diff
N	25	25	25	22	25

Table 5.3: Amount of accessible data sets.

5.7 Procedure

We informed the participants about the importance of dynamic sitting

Before the experiment began, we welcomed the participants. We explained the experiment procedure while emphasizing the importance of dynamic sitting and the assumption that there is no scientific consensus on an "optimal" sitting posture. The subjects were informed about data protection and processing of personal data, risks, compensation, and the interview duration. They signed a consent form which can be found in Appendix B.

We dressed the participants in the Awinda System and ran the calibration procedure

The two-hour study began by dressing the participants in the Xsens Awinda MTw Sensor System for the configuration "Upper Body No Hands", which required the nine sensor modules described in Section 2.4. We applied the sensors according to the Video Tutorial on the Xsens Tutorial Webpage Prepare Hardware[3] and Sensor Placement[4], using Velcro straps for the pelvis, upper arm and forearm, a headband for the head sensor, and a T-shirt for the sternum and shoulder sensors (see Figure 5.3). Afterwards, we ran the calibration procedure, which begins with three seconds of standing in N-Pose (feet parallel, arms hanging straight from the sides, head facing forward) and afterwards moving around until an audio signal is heard. We checked the calibration results by letting the participants wriggle their extremities as we compared the movements to the output of the MVN Analyze animation. Vocal instructions in the Xsens MVN Analyze Pro software accompanied the calibration procedure.

Participants executed six different task conditions

Subsequently, we introduced the participants to the dual task. We ordered the conditions by a Balanced Latin Square, and each run lasted five minutes.

The NASA-TLX questionnaire has been presented to the participants after every experiment condition

After each run, we presented a questionnaire that was to be filled in by the participant. We decided to use the NASA Task Load Index (NASA-TLX)[5] questionnaire to measure subjective workload during each condition. The questionnaire measures the workload by dividing it into six subscales: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort and Frustration, each comprising 21 levels. The NASA-TLX has been shown to have good reliability and validity [Xiao et al., 2005]. After the partic-

---

[3] https://tutorial.movella.com/video/preparing-hardware-mvn-awinda?wvideo=h4ydfedsvm *(Accessed on 10.04.2023)*

[4] https://tutorial.movella.com/video/placing-straps?wvideo=24s5b1jtdd *(Accessed on 10.04.2023)*

[5] https://humansystems.arc.nasa.gov/groups/tlx/downloads/TLXScale.pdf *(Accessed 10.04.2023)*

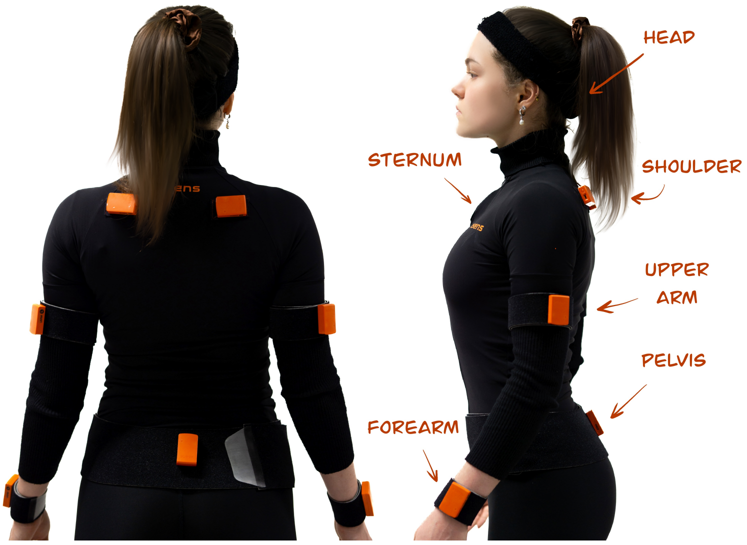

Figure 5.3: The nine sensors were placed according to Xsens Awinda Guidelines. We used the configuration *Upper body, no hands*

ipants had executed each run, we presented an additional questionnaire, asking them to order the condition from best to worst and to justify their decision. The questionnaires are attached in Appendix D. The second part of the experiment consisted of a short presentation of the three different feedback animation prototypes described in Section 4.2.1. After demonstrating idle and feedback states of the associated animation, we presented the participants with an AttrakDiff[6] questionnaire. Lastly, we requested the participants to rank the animations and reveal what they do and do not like about each animation in a final questionnaire.

Participants observed and rated animation prototypes

During the study, snacks and drinks were freely available. After concluding the experiment, we offered the possibility of taking part in a raffle. The prizes were a gift voucher worth 50 €, a free photo shoot and tickets to a trampoline park. The winners were randomly selected and contacted after we finished the recruitment process. In addition, we offered a free *InBody*[7] scan to every interested participant.

Compensations and the possibility to participate in a raffle have been offered to the participants.

---

[6] https://www.attrakdiff.de *(Accessed on 10.04.2023)*
[7] https://de.inbody.com *(Accessed on 10.04.2023)*

5.8 Apparatus

The apparatus for the experiment consisted of the Awinda System, a desk setup and the required software. The hardware was located on a commercially available desk with a chair for the participant to sit on while executing the tasks. The study setup can be seen in Figure 5.4.

5.8.1 Hardware

We used the Xsens MTw Awinda Sensor System with the Sensors for Pelvis, Sternum, Head, left and right Shoulder, Upper Arm and Forearm. For attachment of the sensors to the body, we used the provided Xsens velcro straps and t-shirt, depending on the body measurements of the participant. Other Xsens accessories needed to conduct the study include the Awinda License Stick, router with data and electricity cables, and the MVN tape measure. The desk setup consisted of a computer

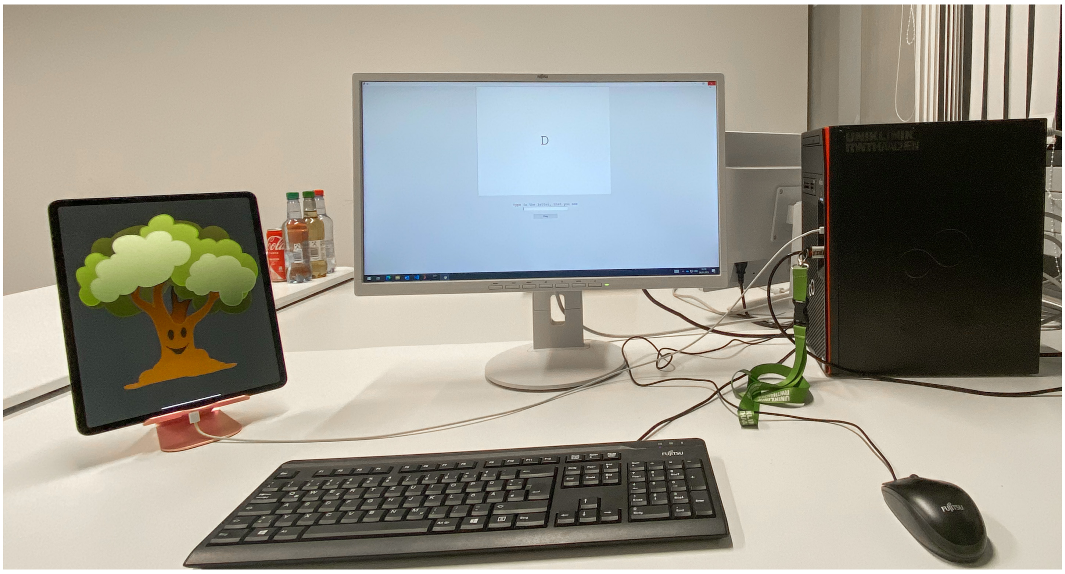

Figure 5.4: The study setup from the perspective of the participants during the tasks. Posture was monitored on a second display from the table on the opposite side of the room.

(Fujitsu ESPRIMO P757/E90 + M16W) with a main display for the participant (Fujitsu B24-8 TE Pro) and a secondary display for the principal investigator (Fujitsu B19-6 LED) to look out for errors during the measurement. A mouse (Fujitsu M-U0026) and a keyboard (Fujitsu KB410 K) were needed for the execution of the tasks. The peripheral feedback was displayed on an iPad (iPad Pro 12.9 2020) in vertical orientation on a stand (OMOTON LYSB0175YDU3M-ELECTRNCS). The iPad was located in the near periphery of the users' field of vision with a rotation of 50° because the performance of the primary task is worse when feedback occurs in the far periphery [Jones et al., 2017, Wickens et al., 2003]. We positioned the iPad on the opposite side of the participants dominant hand, based on our observed preferences for a second monitor. The connection between iPad and the computer was established by a USB-C cable (Apple Thunderbolt 3).

The hardware setup of the study included a desk setup, the Awinda System and an iPad for displaying the peripheral feedback

5.8.2 Software

We used the Software MVN Analyze Pro[8] to establish a connection with the motion system and forward the measured data per UDP connection. We displayed the feedback on the iPad using DUET Display[9] with the DUET Air license. The Scripts and the software ran on a Windows system with Python 3.11.

The software setup of the study required the MVN software, DUET Display for connection with the iPad and the scripts we have developed for this study

The GitLab repository Sitting Posture Guidance[10] contains the implementation scripts that were utilized to perform the user study and implement the feedback system.

---

[8] https://www.movella.com/products/motion-capture/mvn-analyze *(Accessed on 10.04.2023)*

[9] https://de.duetdisplay.com *(Accessed on 10.04.2023)*

[10] https://git.rwth-aachen.de/i10/thesis/thesis-julia-reim-sitting-posture-guidance *(Accessed on 10.04.2023)*

5.9 Results

The NASA-TLX and AttrakDiff results were considered ordinal scales

We used scale rating (NASA-TLX, AttrakDiff) to measure subjective workload and attractiveness. Although the scientific community does not agree on one consensus on whether these scale ratings can be analyzed as ordinal or interval data, we decided to go with the more conservative approach of interpreting these results as ordinal data [Bishop and Herron, 2015].

We analyzed demographic data

First, we evaluated the participants' demographic data and calculated averages and standard deviations. The demographic data is presented in Section 5.6.

The NASA-TLX data was investigated with a Friedman Test

Subsequently, we performed a Friedman Test on each category of the NASA-TLX data. When the Friedman Test supported a significant difference in the category, we performed a Wilcoxon Signed Rank Test with Bonferroni correction as a post-hoc analysis to find where exactly the differences are.

A Two-Way Repeated Measures ANOVA was used to inspect sensor and test data

We calculated a Two-Way Repeated Measures (RM) ANOVA with Feedback and Difficulty as the within-subject factors for the sensor and test data. Factors that showed a significant difference between levels were further analyzed with Tukeys HSD post-hoc test.

5.9.1 Subjective Workload

The Friedman Test showed a significant difference between the experiment conditions in every subscale of the NASA-TLX

A Friedman Test was conducted to analyze whether the subjective workload differs in the subscales of the NASA-TLX questionnaire depending on the difficulty and feedback of the experiment condition. The results show a significant difference in every subscale (see Table 5.4).

Furthermore, we conducted a Wilcoxon Signed Rank post-hoc test with Bonferroni correction to find the exact experiment conditions that differ from one another (see Table 5.4). We found a significant difference between all low and any high mental load conditions in the subscales Mental Demand, Performance, Effort and Frustration. Physical Demand and Temporal Demand showed no significant difference between ML and NFH, NML and NFH, and NFL and NFH. There was no significant difference between NML and NMH, along with NFL and NMH, in the subscale of physical demand.

Further Post Hoc Analysis revealed that the difference occurred between high and low mental load conditions

We found that the conditions with the moving animation scored higher in physical demand than the other conditions during low and high loads (ML and MH). The animation without continuous movement had a higher score in temporal demand during low and high load (NML and NMH) than the other conditions (see Figure 5.5).

ML and MH showed a higher physical demand and NML and NMH a higher temporal demand

		Mental Demand	Physical Demand	Temporal Demand	Performance	Effort	Frustration
p-value		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Effect Size		0.783 (large)	0.249 (small)	0.294 (small)	0.748 (large)	0.762 (large)	0.65 (large)
Post-Hoc							
Group 1	Group 2						
ML	NML	1	1	1	0.811	1	1
ML	NFL	1	1	1	1	1	1
ML	MH	<0.001***	0.005**	0.021*	<0.001***	<0.001***	<0.001***
ML	NMH	<0.001***	0.013*	0.009**	<0.001***	<0.001***	<0.001***
ML	NFH	<0.001***	0.182	0.093	<0.001***	<0.001***	<0.001***
NML	NFL	1	1	1	1	1	1
NML	MH	<0.001***	0.026*	0.018*	<0.001***	<0.001***	<0.001***
NML	NMH	<0.001***	0.177	0.011*	<0.001***	<0.001***	<0.001***
NML	NFH	<0.001***	0.91	0.596	<0.001***	<0.001***	<0.001***
NFL	MH	<0.001***	0.025*	0.028*	<0.001***	<0.001***	<0.001***
NFL	NMH	<0.001***	0.114	0.006**	<0.001***	<0.001***	<0.001***
NFL	NFH	<0.001***	0.1	0.849	<0.001***	<0.001***	<0.001***
MH	NMH	1	1	1	1	1	1
MH	NFH	1	0.726	1	1	1	1
NMH	NFH	1	1	0.562	1	1	1

Table 5.4: Friedman and Wilcoxon Signed Rank Test Results for the NASA-TLX subscales. * 0.01 < p-value < 0.05, ** 0.001 < p-value < 0.01, *** p-value < 0.001

5.9.2 Task Analysis

We ran a Two-Way RM ANOVA to analyze primary and secondary task-dependent variables. Although the individual groups contained some outliers, we kept the affected data sets because the outliers seemed to represent the actual sample data distribution. Due to the sample size and analysis of the distribution plots for each experiment condition,

The primary and secondary tasks were analyzed with a Two-Way RM ANOVA

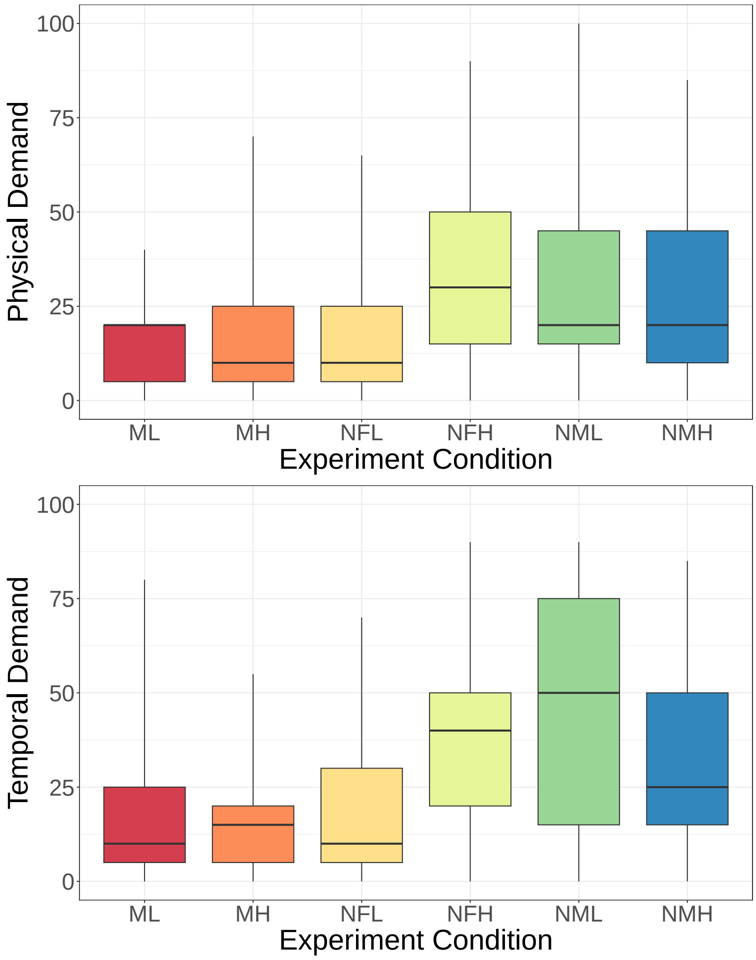

Figure 5.5: NASA TLX temporal demand and physical demand boxplots. ML and MH show a higher mean score in physical demand, and NML and NMH show a higher score in temporal demand of the NASA TLX than other conditions.

we decided to accept the normality assumption. Sphericity was tested with Mauchly's sphericity test, and Greenhouse-Geissler or Huynh-Feldt corrections were applied if necessary. We excluded two participants from the evaluation due to partially missing data, resulting in a sample size of N = 23. Additionally, we asked the original 25 participants to sort each combination of experiment conditions they experienced from best to worst. The results show that ML was preferred, closely followed by NFL and NML. MH was perceived as the worst condition, followed by NH and NMH (see Figure 5.6).

Primary Task

Error Rate and Speed were measured during the primary task

During the primary task of typing a letter into a text field, we measured the error rate and duration for typing in the result after a letter appeared on the screen (speed). The error rate was calculated by dividing the number of wrong answers by the total number of answers (see Equation 5.1). The speed was calculated by subtracting the time when a letter appeared on the screen from the time when the participant pressed the "Okay" button (see Equation 5.2).

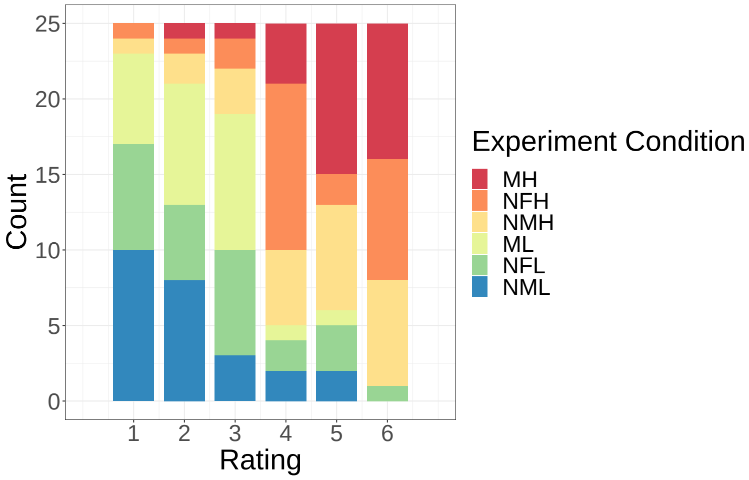

Figure 5.6: Sorting of the six experiment conditions. The participants preferred the conditions with low over those with high cognitive load.

$$errorRate = \frac{wrongAnswers}{rightAnswers + wrongAnswers} \quad (5.1)$$

$$speed = t_{buttonPress} - t_{letterAppearance} \quad (5.2)$$

We found a significant difference in speed and error rate between low and high cognitive load

The results of the Two-Way RM ANOVA show a significant difference in task speed and error rate between the difficulties (see Figure 5.7). There is no interaction effect between Feedback and Difficulty (see Table 5.5). The Difficulty factor consists of only two factor levels; thus, conducting a Post-Hoc Test was unnecessary.

Condition	Speed (s)		Error Rate	
	p-value	F-value	p-value	F-value
Feedback	0.183	1.694	0.87	0.137
Difficulty	<0.001***	18.611	<0.001***	46.654
Interaction	0.915	0.089	0.892	0.114

Table 5.5: Two-Way RM ANOVA Results for Speed and Error Rate of the Primary Task. *** p-value < 0.001

Secondary Task

The speed of changing posture after feedback occurrence was measured for the secondary task

The secondary task corresponded to paying attention to ones sitting posture and changing the posture after feedback occurred. We measured the time needed to change the posture *postureChangeSpeed* after the occurrence of feedback (see Equation 5.3).

$$postureChangeSpeed = t_{feedbackEnd} - t_{feedbackStart} \quad (5.3)$$

We found a significant difference between Feedback and No-Feedback Condtions

We found a significant difference in *postureChangeSpeed* depending on the feedback (see Table 5.6). Afterwards, we performed a Tukey Honestly Significant Difference (Tukey HSD) test to find where the differences occurred. The

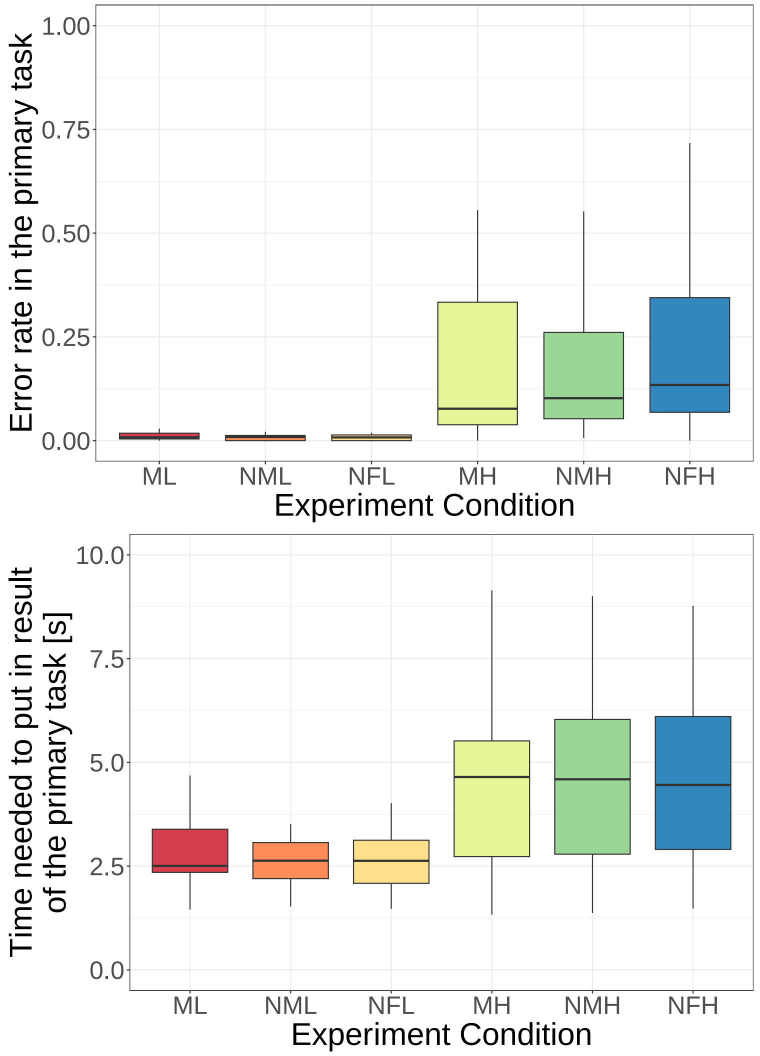

Figure 5.7: Error rate and speed boxplots for each experiment condition. The error rate and speed showed significant differences between difficulties.

Tukey HSD test showed significant differences between the No-Feedback Condition and the Feedback Conditions (see Figure 5.8) where the No-Feedback Condition had a *postureChangeSpeed* that was 28.85 seconds longer than the animation with continuous movement and 30.94 second longer than the animation without continuous movement. There was no significant difference between the two animations.

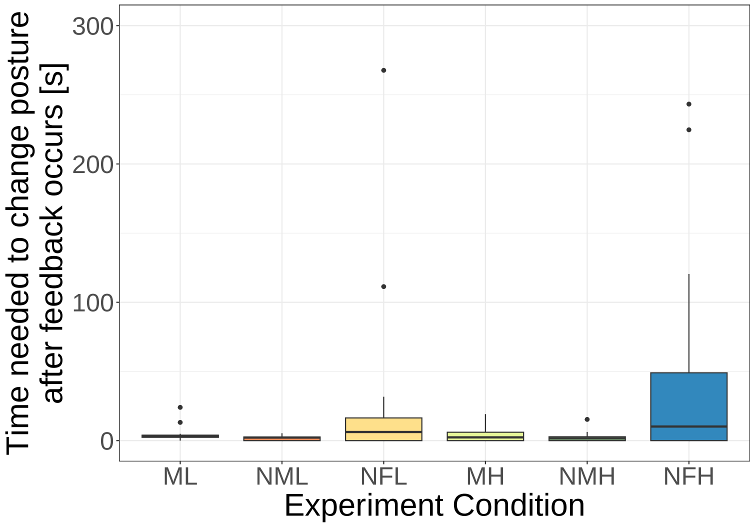

Figure 5.8: Posture change speed boxplots for each condition. It took participants significantly longer to change their posture when there was no feedback, especially during high cognitive load.

Participants sat longest in posture medium-risk 1 and incorporated lateral bending and axial rotation when reacting to feedback

Additionally, we analyzed the posture categories that participants were in during the whole measurement, just before the feedback and to which posture they shifted after they reacted to the feedback. We found that participants were sitting longest in the medium-risk 1 posture for about 40% of the time, about 15% of the time in the low-risk posture and less than 10% in the bending, rotation, medium-risk 2 and high-risk postures. The postures triggering feedback were mostly the medium-risk 1 posture, and participants switched into postures bending, rotation and low-risk after the feedback. However, the data points have a high standard deviation, making retrieving reliable results challenging. Boxplots of the data can be found in Appendix E.

5.9.3 Attractiveness

Attractiveness was measured by the AttrakDiff questionnaire. On 28 bipolar scales, each consisting of seven levels, the attractiveness of a user interface can be measured.

Condition	Posture Change Speed (s)	
	p-value	F-value
Feedback	<0.001***	9.955
Difficulty	0.313	1.026
Interaction	0.404	0.912

Table 5.6: Two-Way RM ANOVA Results for Speed of Posture Change after Feedback, *** p-value < 0.001

We used the AttrakDiff questionnaire to evaluate the attractiveness of the animation prototypes

However, we dropped seven irrelevant items to avoid confusion among the participants [Lewis and Sauro, 2017], resulting in 21 bipolar scales. The AttrakDiff questionnaire can be divided into three distinct qualities: Hedonic Quality - Stimulation (HQS), Hedonic Quality - Identification (HQI) and Attractiveness (ATT). HQS refers to the ability of a product to improve one's skills or knowledge, HQI describes the ability of a product to communicate its value to other people, and ATT refers to the general rating of the product [Hassenzahl, 2004].

The Tree performed best in AttrakDiff scores, followed by the abstraction. The spine was not perceived as well, although the mean scores were located on the positive side of the scale

We visualized each AttrakDiff score for each animation prototype. We found that they generally were perceived on the positive side: The mean value on most scales was larger than 4 with some exceptions where it slightly falls behind (see Figure 5.9). The participants evaluated the abstraction as technical, while the tree was perceived as most human. The abstraction has higher or equal values to the tree only in being perceived as more stylish and of equal premium quality. The abstraction falls behind the tree in the mean of every other score. The spine scores are located more on the lower side of the scores, where the connotation is negative. However, it is perceived as more straightforward than the tree and just as predictable. Additionally, it is perceived as more captivating, predictable, straightforward and human than the abstraction and just as novel and inventive. The tree deviates from the other animations in being appealing, clearly structured, good, creative, inviting, presentable, likable and motivating. The participants perceive the spine as more repelling, rejecting, disagreeable, ugly and unpleasant than the other prototypes. The tree tree was perceived most positive, succeeded by the abstraction, and ultimately, the spine.

Additionally, we evaluated the three prototypes based on the boxplots of the three qualities that the AttrakDiff considers (ATT, HQS, HQI). The tree has the highest and the spine the lowest ATT score of the prototypes. HQI and HQS do not differ much between the prototypes, with the abstraction having a lightly higher score in HQI when compared to the Tree and Spine, and the HQS score is slightly higher in the tree.

The Tree has the highest score in HQS and ATT. The Abstractions shows the highest score in HQI

We asked the participants what animation they would choose for sitting posture guidance. Most participants decided on the tree, five participants decided on the Abstraction or the Spine each and one participant suggested their idea of simple colour changes from green to red. This is also reflected in the results of the prototype ranking 5.9.

The participants preferred the tree over the other two prototypes

Qualitative Analysis

In this section, we will include direct quotations from our study's participants. We translated some of the quotations from German to English to increase readability.

High cognitive load was more mentally demanding than low load

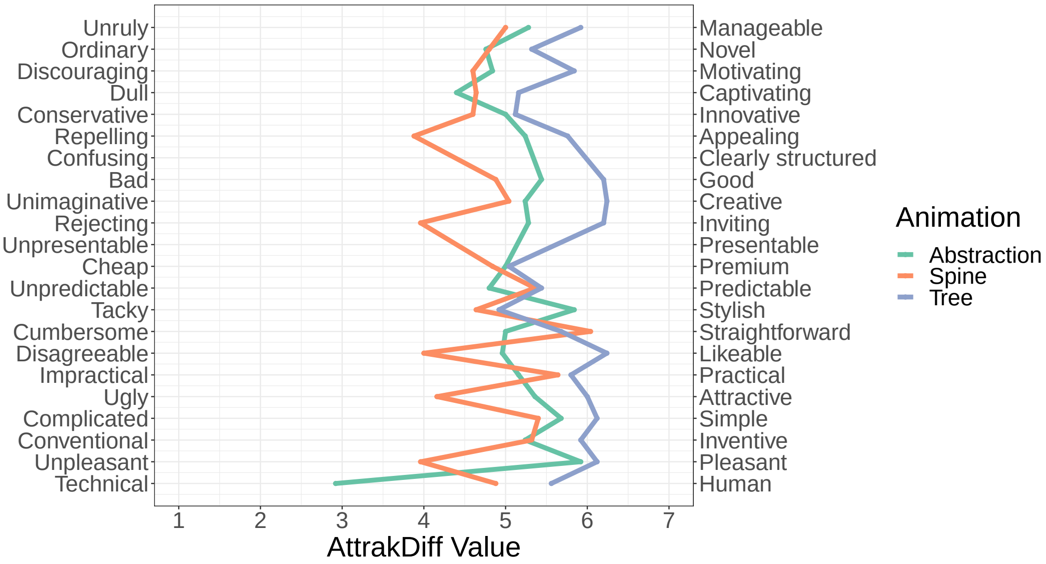

Figure 5.9: The mean scores of the AttrakDiff questionnaire. All of the animations were perceived positively.

Most participants experienced the high cognitive load task as more mentally demanding and stressful compared to the low cognitive load task, giving those tasks a lower rating.

Some perceived the no-feedback conditions as more manageable than the feedback conditions

Some participants stated that the no-feedback conditions were better than the feedback conditions because they only had to pay attention to one task and not to additional feedback. These statements have been given although the participants were instructed to still pay attention to their posture even without feedback

Most enjoyed the feedback conditions over the no-feedback conditions

More participants reported enjoying the feedback conditions better than the no-feedback conditions, stating that they have to remind themselves about changing their posture and thus always having to attribute some mental capacity to their posture.

"I am more relaxed when feedback is present because I don't have to remember myself to move."

Feedback was considered particularly important during the high load tasks

While two participants stated that feedback was more disturbing during high-load tasks compared to low-load tasks, most participants agreed that feedback was important, especially during high cognitive-load tasks. They stated that due to the mentally challenging nature of the high cognitive load task, they were being fixated and focused on the task and forgot to move due to that fixation.

"I tended to relax more and make movements during the low load tasks. During high load tasks I was more focused & made less efforts to move."

"I changed my sitting posture a few times during the low cognitive load condition, because I was thinking about it more often [in comparison to daily life]. But when the task is more difficult, you forget about the fact that you have to change your posture. (I would really like to use this during home-office.)"

Most preferred the condition without continuous movement within the feedback conditions

Most participants preferred the condition without continuous movement. They stated that movement appeared more distracting and the colour change of the animation without continuous movement was enough to trigger them into changing their posture.

"Although the task was quite challenging; the feedback was subtle enough to not distract you and was most fun."

"The shaking of the leaves was a little bit too aggressive for me."

However, about 30% of the participants preferred the animation with continuous movement, justifying this statement by stating that it was more interesting, effective and recognizable.

Some liked the condition with continuous movement better

"The feedback without movement was enough for me to recognize but the feedback with movement was of course more effective and in the animation without movement I had to actively check the display to see if the tree was still green."

"The feedback with movement reduces stress during the high cognitive load task because you are triggered more strongly and are able to react much quicker and experience less stress."

Some participants also agreed they would prefer the animation with continuous movement in lower cognitive load tasks for less monotony and the animation without continuous movement in higher cognitive load tasks for less distraction. There were also many statements that there was no recognizable difference between the two animation conditions or that it was so small that it should not change their workload.

Several participants would choose ML over NML and NMH over MH

Overall the feedback was perceived quite well. Participants reported that they liked the feedback's discreetness and the placement on the desk, where the feedback was perfectly visible in the periphery but not too attention-grabbing, even during the high cognitive load task.

The participants liked the feedback

Summarizing the results of the qualitative analysis, most participants preferred the animation without continuous movement because it was less disturbing than the animation with continuous movement and that the feedback conditions were preferred over no-feedback conditions, especially during high load.

The feedback with continuous movement and feedback, in general, were preferred over feedback without continuous movement or no feedback at all

5.10 Discussion

In this section, we will discuss the results of the main user study from section 5.9. We will start by discussing the subjective workload results, followed by the task analysis and ending with the results of the comparison between animation prototypes.

5.10.1 Subjective Workload

The feedback system did not increase subjective workload in our participants

The results of the Friedman Test for the NASA-TLX questionnaire demonstrated a significant difference in all subscales across the experimental conditions. However, we did not observe significant differences in subjective workload between the feedback and no-feedback conditions. This could be attributed to the possibility that certain participants did not actively attempt to monitor their posture when feedback was absent or simply forgot to do so. This observation is consistent with the findings of our qualitative analysis, as discussed in Section 5.9.3. Nevertheless, participants who monitored their posture as instructed, even without feedback, reported that it was more mentally taxing, particularly during high cognitive workload tasks. Given the absence of differences between feedback types, we cannot reject the null hypothesis for *RH7* and *RH8* in Section 5.3.

Participants did not report a difference in movement condition, although some reported being distracted by the movement

Accordingly, participants did not perceive any increased workload associated with either movement condition. Although some participants noted that the animation with continuous movement was more distracting, which is in line with Mairena et al. [2019] and Maglio and Campbell [2000], this effect was not evident in the subjective workload analysis. Our findings indicate that the feedback system did not impose an increased subjective workload on users.

The participants may have had difficulties observing the movement condition

The higher score in physical demand observed for the animation without continuous movement may have arisen from participants experiencing difficulties in monitoring the movement and being slightly more distracted by it than in the absence of movement, which supports the findings of Mairena et al. [2019] and Maglio and Campbell [2000]. Nonetheless, the animation without continuous movement was associated with a slightly higher score in temporal demand, indicating that participants felt more time pressure than the other conditions.

Physical demand did not show any difference between high and low cognitive load without feedback

No significant differences were found in physical and temporal demand between NFL and NFH, potentially because some participants ceased monitoring their posture without feedback, reducing the physical demand for posture adjustments. Likewise, no significant difference in physical demand was found between NML and NMH. The origin of these non-significant differences is unclear and may be attributable to random variation.

5.10.2 Task Analysis

Most preferred the animation without movement

Based on the sorting of each task from best to worst, it is evident that most participants favoured the animation without movement, supporting Mairena et al. [2019] and Maglio and Campbell [2000], who state that continuous movement might be too distracting. Nevertheless, many participants ranked the animation with movement in the first position, although it appeared in ranks four and five compared to the animation without movement. Some orderings on the lower end were observed in the no-feedback condition, which is consistent with our qualitative findings, as some participants who attempted to monitor their posture even without feedback reported difficulty in maintaining attention on the primary task.

The feedback might have appeared more distracting during high cognitive load

As anticipated, the high cognitive load tasks were rated poorly due to their high cognitive demands. However, NFH received a relatively high rating among these conditions, even higher than MH. This suggests that feedback may be somewhat distracting during tasks that require significant cognitive attention but to a lesser extent during easier tasks. This finding contrasts with our qualitative findings, which indicated that participants who attempted to monitor their posture during the no-feedback condition experienced particular difficulty during high cognitive load tasks and preferred feedback.

Primary Task

We found a significant difference in error rate and speed depending on the difficulty of the primary task, which was expected due to the difference in the cognitive load the tasks subjected the participants to.

The feedback system does not interrupt users in their primary task

However, we did not observe any difference between the feedback conditions, indicating that the feedback, independent from the movement factors, did not affect users' performance in the primary task compared to the no-feedback condition. Thus we can reject the null hypothesis in *RH4* and *RH5* in Section 5.3 in favour of the alternative hypothesis. This is a promising finding as it validates our feedback prototype as being at least non-intrusive and not disturbing users during their primary task and suggesting that the feedback from our prototype may be accepted by users and not be ignored or turned off due to being annoying or leading to a decline in performance in the primary task. This result extends the finding of Plaue and Stasko [2007] to the field of sitting posture guidance. Notably, some participants in our study did not even bother to monitor their posture during the no-feedback condition, suggesting that our prototype may even be accepted by users who are not very interested in posture monitoring.

The continuous movement did not influence the performance of the primary task

Regarding the movement conditions, although most participants stated that the moving animation was distracting, it did not affect their performance in the primary task. Therefore, the choice between movement and no movement in the animation appears to be a matter of personal preference rather than an objective measure of effectiveness. Thus we can not reject the null hypothesis of *RH1* and *RH2* in Section 5.3, which falls in contrast to the findings of Mairena et al. [2019] and Maglio and Campbell [2000], who analyzed peripheral information in different setting from sitting posture guidance and office work.

Secondary Task

We have found a significant difference in the *postureChangeSpeed* between the feedback and no-feedback conditions. This suggests that our prototype effectively encourages participants to practice dynamic sitting. As a result, we can reject the null hypothesis of *RH3* (see Section 5.3) in favour of the alternative hypothesis.

The feedback system manages to make the users practice dynamic sitting

We have also found no significant difference between the movement and no-movement conditions, indicating that the moving animation does not provide any performance benefits over the animation without continuous movement, contrary to Mairena et al. [2019]'s and Maglio and Campbell [2000]'s findings. Some participants in the qualitative analysis reported that the moving animation was more attention-grabbing. However, the decision between the moving and not moving animation appears to be a simple matter of user preference.

Continuous movement is not more attention-grabbing than movement only between states

Our findings show no significant difference in the *postureChangeSpeed* in low and high cognitive load conditions. As a result, we cannot reject the null hypothesis of *RH6* (see Section 5.3). This means that we cannot observe the effect of tunnel vision as theorized by Stokes et al. [1990] and Williams [1995] in our experimental setup. However, this is not negative in our case because our feedback system is not disruptive in low nor high cognitive load conditions. Thus, the effect of tunnel vision is unnecessary since we need it only for less interruption during high cognitive load conditions at the cost of less ability to monitor one's posture. In our case, we achieved little interruption without sacrificing the users' ability to monitor their posture.

We can not observe a tunnel effect. However, our system is not interrupting, even during high load, without needing to fall back on a potential tunnel effect

Additionally, we have observed a difference between the *postureChangeSpeed* of high and low cognitive load conditions in the no-feedback condition. This suggests that users are so focused on their primary task that they forget to change their posture. However, our feedback system mitigates this difference, demonstrating its usefulness, especially in high cognitive load conditions.

Our system mitigates decreased posture awareness and dynamic sitting during high cognitive load

5.10.3 Comparison of Animations

It is vital to create an emotional bond between feedback and user

Based on our comparison of the animations and the AttrakDiff questionnaire, we have observed that participants highly value an emotional connection or another incentive to change their posture during feedback. For instance, the anthropomorphic representation of the tree elicited a sense of sadness and pity among the participants, as they wanted to see the tree happy. Similarly, the representation of the spine generated an unpleasant feeling when participants looked at the unhealthy bending. In contrast, the abstract representation needs to be improved in this regard, as a mere change in colour and speed was insufficient to motivate participants to change their posture. One possible improvement for the abstract animation is to make the feedback state even more uncomfortable by using jagged and upsetting shapes instead of the current round bubbles.

Sine we removed some items from the AttrakDiff, we cannot ensure the validity of the standardized questionnaire. Nevertheless, it remains a useful method to assess the perceived quality of animations. According to Lewis and Sauro [2017], eliminating items from standardized tests may not affect their results, but it has the advantage of reducing participants' workload and confusion.

The plain representation of a spine bending excessively might be uncomfortable to sensitive individuals

We have also identified that some individuals experienced discomfort when looking at the "unhealthy" spine bending and even reported phantom pain. Thus, we caution against using such a representation for sensitive individuals. One solution could be to show a less severe kyphosis or use the shape of a human being instead of a spine for representation purposes. However, such changes may reduce the effectiveness of the feedback system.

The tree ranked positively, but spine and abstraction feedback differed from expectations.

The anthropomorphic representation received a positive ranking, which aligns with the results of the preliminary interview. However, the spine did not perform as well as anticipated, whereas the abstraction received more positive feedback than what we initially expected based on the interview results.

Chapter 6

Summary and Future Work

6.1 Summary and Contributions

In this work, we investigated the effectiveness of an anthropomorphic peripheral feedback system for sitting posture guidance. We aimed to understand if the movement of the peripheral feedback resulted in a difference in the performance of the primary or secondary task and to find out if the peripheral nature of the feedback supported the theory of tunnel vision during office work and sitting posture monitoring.

We studied the effectiveness of anthropomorphic, peripheral feedback for sitting posture guidance

First, we conducted a preliminary interview, revealing that participants consider sitting posture an important topic and are willing to improve their posture. However, they still perceive a "straight" posture as optimal, which could lead to discomfort, whereas research recommends dynamic sitting for spine protection and pain avoidance.

Participants feel the need for posture improvement

Participants showed a general demand for real-time feedback and a reward system, with the feedback being customizable, non-interrupting, and discreet in an office setting. Participants wanted to understand why they were doing something wrong and why the alternative was bet-

They want real-time, non-interrupting, customizable feedback ter. There was also a need for a summary or trend display to track progress and improvement.

We developed a peripheral feedback system

Subsequently, we developed a real-time feedback system for posture that utilizes the Xsens Awinda sensor system to measure posture and delivers peripheral feedback when the user surpasses the maximum holding time for a given posture. The system remains in the feedback state until the user shifts positions, transitioning the animation back to the idle state. We created three different feedback animations based on the preliminary interview results but focused on an anthropomorphic representation to appeal to the users' emotions. Our feedback system prototype distinguishes itself from previous feedback systems in the literature by emphasizing the promotion of dynamic sitting, rather than condemning specific postures that have traditionally been perceived as unhealthy.

Our feedback system promotes dynamic sitting

We evaluated our feedback system in a user study

We evaluated our anthropomorphic feedback system in a user study, focusing on the difference in animations with continuous motion or motion only between states and the difference in a high or low cognitive load of the primary task.

Our system works as intended, and continuous movement does not affect the performance of primary and secondary tasks

Our study showed that the feedback system we developed successfully encouraged users to practice dynamic sitting without disrupting their primary task, regardless of their cognitive load and the type of movement in the animation. Furthermore, we could not recreate tunnel vision, which turned out not to matter, as our system provided non-interrupting feedback even during high cognitive loads. Our investigation did not reveal any significant difference in performance between continuous movement and movement only between states, indicating that the choice of movement might be a matter of personal preference.

6.2 Limitations and Future work

Sedentary behaviour is increasing, making posture guidance even more important

Given the continued significance of preserving good posture for overall health and well-being, particularly in light of the surge of work-from-home opportunities that have resulted in increased sedentary behaviour [Stockwell et al., 2021], further investigation and advancement in the field of sitting posture guidance are crucial.

The Awinda system is impractical for everyday use

The Xsens MTw Awinda system used in this study is unsuitable for everyday use due to its high cost, complexity, limited freedom of movement, and lack of aesthetic appeal. A more practical, minimal, and portable measurement system is needed for everyday use, such as earphones [Takayama et al., 2021] or a pressure mat.

The system has to be evaluated in a long-term scenario

The evaluation of the system was brief, with limited maximum holding times. A long-term measurement using a more practical measurement system with increased maximum holding times, such as that used in Tahernejad et al. [2022], could provide more insight into participants' postures throughout a workday. This would include the duration of each posture, the participants' transition postures, and the time spent in the new postures. Data has already been collected, but the analysis is beyond the scope of this thesis.

A level system or trends and statistics could help to make users more interested in posture

A PBL or gardening system similar to that presented in Hong et al. [2015a] could be implemented in upcoming research. Users may be motivated to continue monitoring their sitting posture to maintain their progress, and it could be enjoyable to see how much progress has been made. A summary of previous posture and sitting posture performance statistics may incentivize users to improve their posture further and help them understand why it is necessary.

Context-sensitive interruption could enhance our feedback system

One potential area for enhancement for future research is the implementation of a context-aware interruption system, as presented by Adamczyk and Bailey [2004], which would allow the feedback system to recognize when users are engaged in important or demanding tasks and avoid interrupting them unnecessarily. This feature could be particularly beneficial in work environments where productivity and concentration are highly valued, as it could help users to maintain their focus while still receiving the benefits of the posture feedback system.

Appendix A

Xsens MTw Awinda Segment and Joint Tables

In this section we present the full Tables for the MVN Analyze raw data segment name and indices, as well as joints with their respective number and label

Segment Name	Segment Index
Pelvis	0
L5	1
L3	2
T12	3
T8	4
Neck	5
Head	6
Right Shoulder	7
Right Upper Arm	8
Right Forearm	9
Right Hand	10
Left Shoulder	11
Left Upper Arm	12
Left Forearm	13
Left Hand	14
Right Upper Leg	15
Right Lower Leg	16
Right Foot	17
Right Toe	18
Left Upper Leg	19
Left Lower Leg	20
Left Foot	21
Left Toe	22
Prop1	24
Prop2	25
Prop3	26
Prop4	27

Table A.1: Full segment indices in the UDP data stream from the Xsens network streaming Protocol Specifiaction

Number	Joint Label	Corresponding Joint
1	jL5S1	Joint between the lumbar spine segment 5 and sacral spine 1
2	jL4L3	Joint between the lumbar spine segment 4 and lumbar spine segment 3
3	jL1T12	Joint between the lumbar spine segment 1 and thoracic spine segment 12
4	jT9T8	Joint between the thoracic spine segment 9 and thoracic spine segment 8*
5	jT1C7	Joint between the thoracic spine segment 1 and cervical spine segment 7*
6	jC1Head	Joint between the cervical spine segment 1 and the head segment
7	jRightC7Shoulder	Joint between cervical spine 7 and the right MVN shoulder segment
8	jRightShoulder	Joint angle between the right MVN shoulder segment and the right upper arm
9	jRightElbow	Joint between the right upper arm and the right forearm
10	jRightWrist	Joint between the right forearm and the right hand
11	jLeftC7Shoulder	Joint between cervical spine 7 and the left MVN shoulder segment
12	jLeftShoulder	Joint angle between the left MVN shoulder segment and the left upper arm
13	jLeftElbow	Joint between the left upper arm and the left forearm
14	jLeftWrist	Joint between the left forearm and the left hand
15	jRightHip	Joint between the pelvis and the right upper leg
16	jRightKnee	Joint between the right upper leg and the right lower leg
17	jRightAnkle	Joint between the right lower leg and the right foot
18	jRightBallFoot	Joint between the right foot and the calculated right toe
19	jLeftHip	Joint between the pelvis and the left upper leg
20	jLeftKnee	Joint between the left upper leg and the left lower leg
21	jLeftAnkle	Joint between the left lower leg and the left foot
22	jLeftBallFoot	Joint between the left foot and the calculated left toe

Table A.2: Joint IDs of the Awinda joint angles and their definition. * The joint definitions are not mentioned in the MVN user manual but are theorized by us from the context of the remaining definitions. From the MVN User Manual.

Appendix B

Informed Consent

In this section we present the informed consent forms that each participant of the user study signed. The first consent form relates to the preliminary interview. The second consent form relates to the main user study. The consent form was available in English and German translation.

Informed Consent Form

Understanding User Preferences Regarding Feedback on Sitting Posture

PRINCIPAL INVESTIGATOR Julia Reim
RWTH Aachen University
Phone: +49 1631693797
Email: julia.reim@rwth-aachen.de

Purpose of the study: The goal of this study is to identify user preferences on feedback mechanisms of a posture tracking device. We record the audio over the complete time of the interview and make handwritten notes.

Procedure: The study consists of a semi-structured interview. Participation can take place as a phone-, videochat-, or face-to-face interview. The approximate duration is 30 minutes.

Risks/Discomfort: There are no risks associated with participation in the interview. It will be possible to take breaks when needed. Should completion become distressing to you, it will be terminated immediately.

Benefits: The results of this study will be used to create feedback methods for a posture sensing device.

Alternatives to Participation: Participation in this study is voluntary. You are free to withdraw or discontinue the participation.

Cost and Compensation: Participation in this study will involve no cost or compensation to you.

Confidentiality: All information collected during the study period will be kept strictly confidential. You will be identified through identification numbers. No publications or reports from this project will include identifying information on any participant. If you agree to join this study, please sign your name below.

_____ I have read and understood the information on this form.
_____ I have had the information on this form explained to me.

Participant's Name	Participant's Signature	Date
	Principal Investigator	Date

If you have any questions regarding this study, please contact the principal investigators.

Informed Consent Form

Understanding User Preferences Regarding Feedback on Sitting Posture

PRINCIPAL INVESTIGATOR	Julia Reim RWTH Aachen University Phone: +49 163 1693797 Email: julia.reim@rwth-aachen.de

Purpose of the study: The goal of this study is to identify user preferences on peripheral feedback of a posture tracking device. Participants will be asked to perform a computer task while wearing the Xsens MTw Awinda Sensor System and monitoring their posture. The participants posture data and task performance will be recorded.

Procedure: Participation in this study will involve six phases. In each phase, the participant will have to complete a computer task in one of two levels of difficulty while monitoring the peripheral feedback that appears on a second screen. After each set, you are asked to fill out a questionnaire about the tested feedback. You will be asked to put on the Awinda Sensor System and take part in the calibration beforehand. After the six phases, you will be asked to fill out a questionnaire regarding three different peripheral feedback animations that will be presented to you. This study should take about 90-120 minutes to complete.

Risks/Discomfort: You will be given several opportunities to rest, and additional breaks are also possible. There are no other risks associated with participation in the study. Should completion of either the task or the questionnaire become distressing to you, it will be terminated immediately.

Benefits: The results of this study will be used to create feedback methods for a posture sensing device.

Alternatives to Participation: Participation in this study is voluntary. You are free to withdraw or discontinue the participation.

Cost and Compensation: Participation in this study will involve no cost to you. There will be snacks and drinks for you during and after the participation. You can voluntarily enter into a raffle to win a small prize.

Confidentiality: All information collected during the study period will be kept strictly confidential. You will be identified through identification numbers. No publications or reports from this project will include identifying information on any participant. If you agree to join this study, please sign your name below.

_____ I have read and understood the information on this form.
_____ I have had the information on this form explained to me.

Participant's Name	Participant's Signature	Date
	Principal Investigator	Date

If you have any questions regarding this study, please contact the principal investigators.

Appendix C

Preliminary Interview Questions

This section provides the questions of the preliminary interview.

Preliminary Interview Questions

1. How long on average, do you sit per day?

2. Have you ever tried to optimize your sitting posture?
    - If yes, how did you go about it?

3. How do you define a healthy sitting posture?

4. Do you think you have a healthy sitting posture while working at a desk?
    - If not, what keeps you from having a healthy sitting posture?

5. What feedback would you *like* to get from a smart, posture-supporting device? (Open question)

6. What feedback would you *dislike* receiving from a smart, posture-supporting device? (Open question)

7. Please sort the following feedback modalities starting from most liked to least liked.
    - Sound/Audio
    - Visual Feedback on a primary screen
    - Visual Feedback on a peripheral screen
    - Haptic Feedback (Vibration)
    - Warmth

8. Applied to a peripheral display, how would you rate the following visual representations of posture on a scale from 1 to 5, where 5 means you particularly like the representation and 1 means you don't like the representation at all?
    - Flower
    - Tree
    - Person
    - Animal
    - Minimalistic Shape
    - Abstraction of the spine
    - Abstract colors or brightness levels
    - Scale

9. Do you have any additional ideas or preferences regarding peripheral feedback?

10. Related to posture detection: Would you prefer to wear a measurement system on your body (e.g., smartwatch or headphones) or to have it integrated in the environment (e.g., chair with pressure sensors or camera)?

11. Which characteristics should a posture feedback meet to be useful for you? (5 Point Likert Scale from strongly disagree to strongly agree).
    - It should not distract me from my main activity
    - It should be consistent with my aesthetic preferences
    - It should be discreet
    - It should be a feedback method that I already know
    - It should be customizable

12. Are there any other features that would be important to you? (Open Question)

Appendix D

User Study Questionnaires

This section provides the English questionnaires used during the main user study. First participants were asked to answer questions regarding their demographic data. After each run of the condition study, we asked them to fill out a NASA-TLX questionnaire and after six runs were completed, the participants filled out a comparative questionnaire. Afterwards we asked participants to fill out an AttrakDiff questionnaire for each animation prototype and also fill out a comparative questionnaire afterwards. Finally the participants were presented with the final, optional questionnaire regarding the raffle and an optional InBody measurement

Age:

Height:

Gender:

Foot length:

Do you suffer from any illnesses of the Spine? If yes, which ones?

Did you have any previous surgeries of the spine? If yes, what surgeries?

How many hours per day do you spend sitting?

☐ Less then 3

☐ Between 3 and 6 hours

☐ More then 6 hours.

What hand do you use to operate the computer mouse?

☐ right

☐ left

Mental Demand

How mentally demanding was the task?

Very Low Very High

Physical Demand

How physically demanding was the task?

Very Low Very High

Temporal Demand

How hurried or rushed was the pace of the task?

Very Low Very High

Performance

How successful were you in accomplishing what you were asked to do?

Perfect Failure

Effort

How hard did you have to work to accomplish your level of performance?

Very Low Very High

Frustration

How insecure, discourage, irritated, stressed, and annoyed were you?

Very Low Very High

Please sort the 6 conditions. From what you liked the most to what you liked the least.

A: Peripheral Feedback, Continuous Movement, High Load
B: Peripheral Feedback, Continuous Movement, Low Load
C: Peripheral Feedback, No Movement, High Load
D: Peripheral Feedback, No Movement, Low Load
E: No Feedback, High Load
F: No Feedback, Low Load

	1	2	3	4	5	6	
Best							Worst

Please justify your decision:

Please provide your impressions of the product you have tested by check marking your impression on the scale between the terms offered in each line.

	1	2	3	4	5	6	7	
Human	☐	☐	☐	☐	☐	☐	☐	Technical
Pleasant	☐	☐	☐	☐	☐	☐	☐	Unpleasant
Inventive	☐	☐	☐	☐	☐	☐	☐	Conventional
Simple	☐	☐	☐	☐	☐	☐	☐	Complicated
Ugly	☐	☐	☐	☐	☐	☐	☐	Attractive
Practical	☐	☐	☐	☐	☐	☐	☐	Impractical
Likeable	☐	☐	☐	☐	☐	☐	☐	Disagreeable
Cumbersome	☐	☐	☐	☐	☐	☐	☐	Straightforward
Stylish	☐	☐	☐	☐	☐	☐	☐	Tacky
Predictable	☐	☐	☐	☐	☐	☐	☐	Unpredictable
Cheap	☐	☐	☐	☐	☐	☐	☐	Premium
Unpresentable	☐	☐	☐	☐	☐	☐	☐	Presentable
Rejecting	☐	☐	☐	☐	☐	☐	☐	Inviting
Unimaginative	☐	☐	☐	☐	☐	☐	☐	Creative
Good	☐	☐	☐	☐	☐	☐	☐	Bad
Confusing	☐	☐	☐	☐	☐	☐	☐	Clearly structured
Repelling	☐	☐	☐	☐	☐	☐	☐	Appealing
Innovative	☐	☐	☐	☐	☐	☐	☐	Conservative
Dull	☐	☐	☐	☐	☐	☐	☐	Captivating
Motivating	☐	☐	☐	☐	☐	☐	☐	Discouraging
Novel	☐	☐	☐	☐	☐	☐	☐	Ordinary
Unruly	☐	☐	☐	☐	☐	☐	☐	Manageable

If you could choose one animation, which one would it be?

☐ Tree
☐ Abstraction (Bubbles)
☐ Spine
☐ Other:

Please sort the three presented animations: Tree, Abstraction, Spine

I like it the most	
I like it mediocre	
I like it the least	

This is what I liked about the animation **Tree**:

This could be better in the animation **Tree:**

This is what I liked about the animation **Abstraction**:

This could be better in the animation **Abstraction**:

This is what I liked about the animation **Spine**:

This could be better in the animation **Spine**:

Which animation would motivate you in the long run? Justify please.

Raffle

I, _______________________________________, would like to participate in the following raffles:

☐ 50 Euro Coupon

☐ 1 Hour Fotoshooting with Dmitry Ewig

☐ SuperFly Aachen gift box (2 x VIP tickets 60 minutes, 2 x socks, 2x ribbons)

InBody Measurement

Each participant is offered a free InBody body measurement. The results of the measurement will be sent by mail. The participation is voluntary.

☐ I would like a free InBody measurement. The results of the measurement may be used pseudonymously for research purposes. I can revoke my consent at any time.

E-Mail-Address:

____

Signature

Appendix E

Postures During the Experiment

In this section we present three graphs representing the postures that participants assumed during the whole experiment (Figure E.1), just before feedback occurred (Figure E.2) and which posture they shifted to after they reacted to the feedback (Figure E.3).

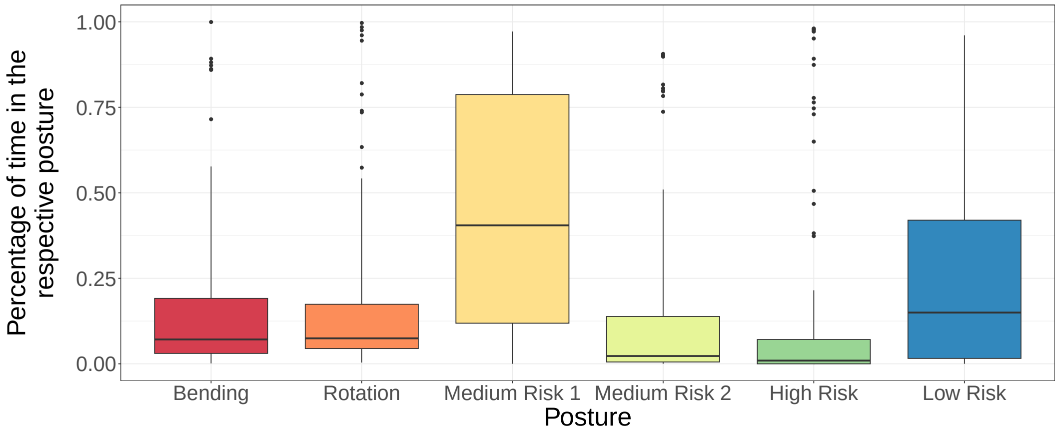

Figure E.1: Percentage of total time participants sat in the respective position

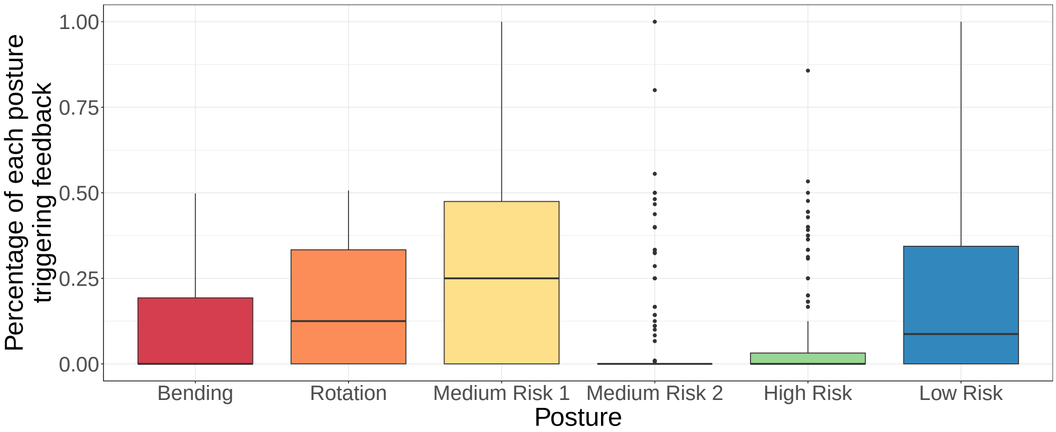

Figure E.2: Percentage of time participants sat in the respective position triggering feedback

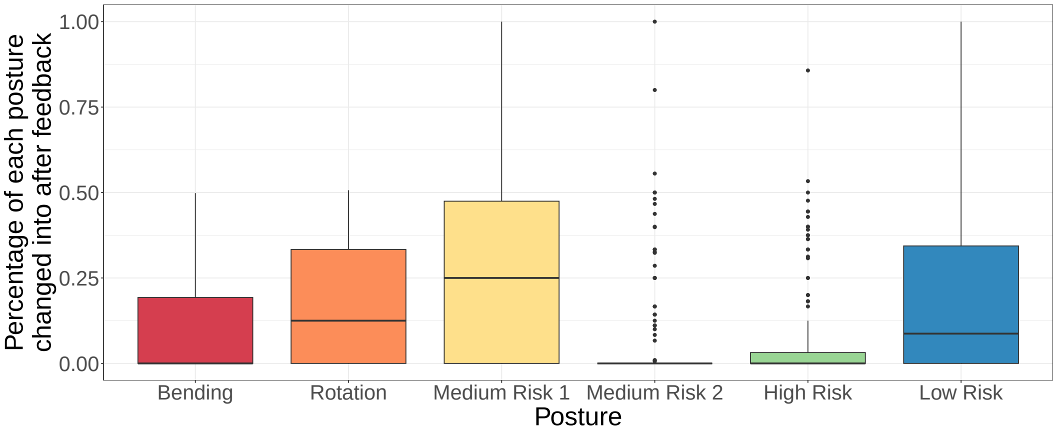

Figure E.3: Percentage of time participants sat in the respective position reacting to feedback

Bibliography

Fatemeh Abyarjoo, Nonnarit O-Larnnithipong, Sudarat Tangnimitchok, Francisco Ortega, and Armando Barreto. Posturemonitor: real-time imu wearable technology to foster poise and health. In *Design, User Experience, and Usability: Interactive Experience Design: 4th International Conference, DUXU 2015, Held as Part of HCI International 2015, Los Angeles, CA, USA, August 2-7, 2015, Proceedings, Part III 4*, pages 543–552. Springer, 2015. URL `https://doi.org/10.1007/978-3-319-20889-3_50`.

Piotr D. Adamczyk and Brian P. Bailey. If not now, when? the effects of interruption at different moments within task execution. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '04, page 271–278, New York, NY, USA, 2004. Association for Computing Machinery. ISBN 1581137028. URL `https://doi.org/10.1145/985692.985727`.

Norhafizan Ahmad, Raja Ariffin Raja Ghazilla, Nazirah M Khairi, and Vijayabaskar Kasi. Reviews on various inertial measurement unit (imu) sensor applications. *International Journal of Signal Processing Systems*, 1(2):256–262, 2013. URL `https://doi.org/10.12720/ijsps.1.2.256-262`.

Gertje A M Ariëns, Paulien M Bongers, Marjolein Douwes, Michael C Miedema, Wilhelmina E Hoogendoorn, Gerrit van der Wal, Lex M Bouter, and Willem van Mechelen. Are neck flexion, neck rotation, and sitting at work risk factors for neck pain? results of a prospective cohort study. *Occupational and environmental medicine*, 58(3):200–207, 2001. URL `https://doi.org/10.1136/oem.58.3.200`.

Katarzyna Barczyk-Pawelec and Tomasz Sipko. Active self-correction of spinal posture in pain-free women in response to the command “straighten your back”. *Women & health*, 57(9):1098–1114, 2017. URL `https://doi.org/10.1080/03630242.2016.1243605`.

Jeff M Barrett, Colin McKinnon, and Jack P Callaghan. Cervical spine joint loading with neck flexion. *Ergonomics*, 63 (1):101–108, 2020. URL `https://doi.org/10.1080/00140139.2019.1677944`.

Lyn Bartram, Colin Ware, and Tom Calvert. Moticons:: detection, distraction and task. *International Journal of Human-Computer Studies*, 58(5):515–545, 2003. URL `https://doi.org/10.1016/S1071-5819(03)00021-1`.

Anne Benjaminse, Ruben Bolt, Alli Gokeler, and Bert Otten. A validity study comparing xsens with vicon. *ISBS Proceedings Archive*, 38(1):752, 2020.

Jeremy Birnholtz, Lindsay Reynolds, Eli Luxenberg, Carl Gutwin, and Maryam Mustafa. Awareness beyond the desktop: exploring attention and distraction with a projected peripheral-vision display. In *Proceedings of Graphics Interface 2010*, GI ’10, pages 55–62. Canadian Information Processing Society, 2010. ISBN 9781568817125.

Phillip A Bishop and Robert L Herron. Use and misuse of the likert item responses and other ordinal measures. *International journal of exercise science*, 8(3):297, 2015.

Rosemary A Bonney and Esmond Nigel Corlett. Head posture and loading of the cervical spine. *Applied ergonomics*, 33(5):415–417, 2002. URL `https://doi.org/10.1016/s0003-6870(02)00036-4`.

Carolin Bontrup, William R Taylor, Michael Fliesser, Rosa Visscher, Tamara Green, Pia-Maria Wippert, and Roland Zemp. Low back pain and its relationship with sitting behaviour among sedentary office workers. *Applied ergonomics*, 81:102894, 2019. URL `https://doi.org/10.1016/j.apergo.2019.102894`.

Alberto Bucciero, Stefano Santo Sabato, and Marco Zappatore. A biomechanical analysis system of posture. PervasiveHealth ’14, page 41–48, Brussels, BEL, 2014. ICST

(Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering). ISBN 9781631900112. URL `https://doi.org/10.4108/icst.pervasivehealth.2014.254944`.

Daniela Chudá and Kamil Burda. Toward posture recognition with touch screen biometrics. In *Proceedings of the 17th International Conference on Computer Systems and Technologies 2016*, CompSysTech '16, page 293–299, New York, NY, USA, 2016. Association for Computing Machinery. ISBN 9781450341820. URL `https://doi.org/10.1145/2983468.2983525`.

Andrew P Claus, Julie A Hides, G Lorimer Moseley, and Paul W Hodges. Is 'ideal'sitting posture real?: Measurement of spinal curves in four sitting postures. *Manual therapy*, 14(4):404–408, 2009. URL `https://doi.org/10.1016/j.math.2008.06.001`.

Andrew P Claus, Julie A Hides, Lorimer G Moseley, and Paul W Hodges. Thoracic and lumbar posture behaviour in sitting tasks and standing: Progressing the biomechanics from observations to measurements. *Applied ergonomics*, 53:161–168, 2016. URL `https://doi.org/10.1016/j.apergo.2015.09.006`.

Enrico Costanza, Samuel A Inverso, Elan Pavlov, Rebecca Allen, and Pattie Maes. Eye-q: Eyeglass peripheral display for subtle intimate notifications. In *Proceedings of the 8th conference on Human-computer interaction with mobile devices and services*, pages 211–218, 2006. URL `https://doi.org/10.1145/1152215.1152261`.

Gregory D. Cramer. Chapter 2 - general characteristics of the spine. In Gregory D. Cramer and Susan A. Darby, editors, *Clinical Anatomy of the Spine, Spinal Cord, and Ans (Third Edition)*, pages 15–64. Mosby, Saint Louis, third edition edition, 2014. ISBN 978-0-323-07954-9. URL `https://doi.org/10.1016/B978-0-323-07954-9.00002-5`.

Jason M Cuéllar and Todd H Lanman. "text neck": an epidemic of the modern era of cell phones? *The Spine Journal*, 17(6):901–902, 2017. URL `https://doi.org/10.1016/j.spinee.2017.03.009`.

Andrew Dahley, Craig Wisneski, and Hiroshi Ishii. Water lamp and pinwheels: Ambient projection of digital information into architectural space. In *CHI 98 Conference Summary on Human Factors in Computing Systems*, CHI '98, page 269–270, New York, NY, USA, 1998. Association for Computing Machinery. ISBN 1581130287. URL `https://doi.org/10.1145/286498.286750`.

Ioana Daian, Annemieke M Van Ruiten, Albertine Visser, and Senka Zubic. Sensitive chair: a force sensing chair with multimodal real-time feedback via agent. In *Proceedings of the 14th European conference on Cognitive ergonomics: invent! explore!*, pages 163–166, 2007. URL `https://doi.org/10.1145/1362550.1362583`.

Diana E De Carvalho, David Soave, Kim Ross, and Jack P Callaghan. Lumbar spine and pelvic posture between standing and sitting: a radiologic investigation including reliability and repeatability of the lumbar lordosis measure. *Journal of manipulative and physiological therapeutics*, 33(1):48–55, 2010. URL `https://doi.org/10.1016/j.jmpt.2009.11.008`.

Paul Duffy and Alan F Smeaton. Measuring the effectiveness of user interventions in improving the seated posture of computer users. In *Evolving Ambient Intelligence: AmI 2013 Workshops, Dublin, Ireland, December 3-5, 2013. Revised Selected Papers 4*, pages 3–12. Springer, 2013. URL `https://doi.org/10.1007/978-3-319-04406-4_2`.

Stephen J Edmondston, Hon Yan Chan, Gorman Chi Wing Ngai, Linda M Warren, Jonathan M Williams, Susan Glennon, and Kevin Netto. Postural neck pain: an investigation of habitual sitting posture, perception of 'good'posture and cervicothoracic kinaesthesia. *Manual therapy*, 12(4):363–371, 2007. URL `https://doi.org/10.1016/j.math.2006.07.007`.

Anja Exler, Zeynep Günes, and Michael Beigl. Preferred notification modalities depending on the location and the location-based activity. UbiComp/ISWC '19 Adjunct, page 1064–1069, New York, NY, USA, 2019. Association for Computing Machinery. ISBN 9781450368698. URL `https://doi.org/10.1145/3341162.3344842`.

Kazuyuki Fujita, Aoi Suzuki, Kazuki Takashima, Kaori Ikematsu, and Yoshifumi Kitamura. Tiltchair: Manipulative posture guidance by actively inclining the seat of an office chair. CHI '21, New York, NY, USA, 2021. Association for Computing Machinery. ISBN 9781450380966. URL `https://doi.org/10.1145/3411764.3445151`.

Hans-W. Gellersen, Albrecht Schmidt, and Michael Beigl. Ambient media for peripheral information display. *Personal and ubiquitous computing*, 3(4):199–208, 1999. ISSN 0949-2054, 1617-4917. doi: 10.1007/bf01540553. URL `https://doi.org/10.1007/bf01540553`.

RHM Goossens, MP Netten, and B Van der Doelen. An office chair to influence the sitting behavior of office workers. *Work*, 41(Supplement 1):2086–2088, 2012. URL `https://doi.org/10.3233/wor-2012-0435-2086`.

Franz Grehn and Wolfgang Leydhecker. *Augenheilkunde*, volume 30. Springer, 2012. URL `https://doi.org/10.1007/978-3-662-59154-3`.

Xiaofei Guan, Guoxin Fan, Zhengqi Chen, Ying Zeng, Hailong Zhang, Annan Hu, Guangfei Gu, Xinbo Wu, Xin Gu, and Shisheng He. Gender difference in mobile phone use and the impact of digital device exposure on neck posture. *Ergonomics*, 59(11):1453–1461, 2016. URL `https://doi.org/10.1080/00140139.2016.1147614`.

Michael Haller, Christoph Richter, Peter Brandl, Sabine Gross, Gerold Schossleitner, Andreas Schrempf, Hideaki Nii, Maki Sugimoto, and Masahiko Inami. Finding the right way for interrupting people improving their sitting posture. In *Human-Computer Interaction–INTERACT 2011: 13th IFIP TC 13 International Conference, Lisbon, Portugal, September 5-9, 2011, Proceedings, Part II 13*, pages 1–17. Springer, 2011. URL `https://doi.org/10.1007/978-3-642-23771-3_1`.

Marc Hassenzahl. Mit dem AttrakDiff die attraktivität interaktiver produkte messen. *Tagungsband UP04*, pages 96–102, 2004.

Eric Hermand, Bertrand Tapie, Olivier Dupuy, Sarah Fraser, Maxence Compagnat, Jean Yves Salle, Jean Christophe

Daviet, and Anaick Perrochon. Prefrontal cortex activation during dual task with increasing cognitive load in subacute stroke patients: A pilot study. *Frontiers in aging neuroscience*, 11:160, 2019. URL `https://doi.org/10.3389/fnagi.2019.00160`.

Jeong-Ki Hong, Bon-Chang Koo, So-Ryang Ban, Jun-Dong Cho, and Andrea Bianchi. Beupo: A digital plant that you can raise and customize with your current posture. In *Adjunct Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2015 ACM International Symposium on Wearable Computers*, UbiComp/ISWC'15 Adjunct, page 1015–1020, New York, NY, USA, 2015a. Association for Computing Machinery. ISBN 9781450335751. URL `https://doi.org/10.1145/2800835.2800953`.

Jeong-ki Hong, Sunghyun Song, Jundong Cho, and Andrea Bianchi. Better posture awareness through flower-shaped ambient avatar. In *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction*, TEI '15, page 337–340, New York, NY, USA, 2015b. Association for Computing Machinery. ISBN 9781450333054. URL `https://doi.org/10.1145/2677199.2680575`.

Adrian G Horridge. The evolution of visual processing and the construction of seeing systems. *Proceedings of the Royal Society of London. Series B, Biological Sciences*, 230(1260):279–292, 1987. ISSN 00804649. URL `https://doi.org/10.1098/rspb.1987.0020`.

Eric Horvitz, Edward Cutrell, and Mary Czerwinski. Notification, disruption, and memory: Effects of messaging interruptions on memory and performance. In *Human-Computer Interaction: INTERACT*, volume 1, page 263, 2001.

Damian Hoy, Lyn March, Peter Brooks, Fiona Blyth, Anthony Woolf, Christopher Bain, Gail Williams, Emma Smith, Theo Vos, Jan Barendregt, et al. The global burden of low back pain: estimates from the global burden of disease 2010 study. *Annals of the rheumatic diseases*, 73 (6):968–974, 2014. URL `https://doi.org/10.1136/annrheumdis-2013-204428`.

Haruna Ishimatsu and Ryoko Ueoka. Finding the right feedback for self-posture adjustment system for "bitaika". In *SIGGRAPH Asia 2015 Posters*, SA '15, New York, NY, USA, 2015. Association for Computing Machinery. ISBN 9781450339261. URL `https://doi.org/10.1145/2820926.2820972`.

Kaspar Jansen, Bailey Tarren, and Mascha Slingerland. Disposable, stretchable on-skin sensors for posture monitoring. WearSys '18, page 1–4, New York, NY, USA, 2018. Association for Computing Machinery. ISBN 9781450358422. URL `https://doi.org/10.1145/3211960.3211969`.

Prawit Janwantanakul, Praneet Pensri, Viroj Jiamjarasrangsri, and Thanes Sinsongsook. Prevalence of self-reported musculoskeletal symptoms among office workers. *Occupational medicine*, 58(6):436–438, 2008. URL `https://doi.org/10.1093/occmed/kqn072`.

Lee Jones, John McClelland, Phonesavanh Thongsouksanoumane, and Audrey Girouard. Ambient notifications with shape changing circuits in peripheral locations. In *Proceedings of the 2017 ACM International Conference on Interactive Surfaces and Spaces*, ISS '17, page 405–408, New York, NY, USA, 2017. Association for Computing Machinery. ISBN 9781450346917. URL `https://doi.org/10.1145/3132272.3132291`.

Kaja Kastelic, Žiga Kozinc, and Nejc Šarabon. Sitting and low back disorders: an overview of the most commonly suggested harmful mechanisms. *Collegium antropologicum*, 42(1):73–79, 2018.

Ivan Kesedžić, Marko Šarlija, Jelena Božek, Siniša Popović, and Krešimir Ćosić. Classification of cognitive load based on neurophysiological features from functional near-infrared spectroscopy and electrocardiography signals on n-back task. *IEEE Sensors Journal*, 21(13):14131–14140, 2020. URL `https://doi.org/10.1109/JSEN.2020.3038032`.

Rushil Khurana, Elena Marinelli, Tulika Saraf, and Shan Li. Neckgraffe: a postural awareness system. In *CHI'14 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '14, pages 227–232. Association for Computing Machinery, 2014. ISBN 9781450324748. URL `https://doi.org/10.1145/2559206.2580936`.

Joohee Kim, Na Hyeon Lee, Byung-Chull Bae, and Jun Dong Cho. A feedback system for the prevention of forward head posture in sedentary work environments. In *Proceedings of the 2016 ACM Conference Companion Publication on Designing Interactive Systems*, DIS '16 Companion, page 161–164, New York, NY, USA, 2016. Association for Computing Machinery. ISBN 9781450343152. URL `https://doi.org/10.1145/2908805.2909414`.

Vasileios Korakakis, Kieran O'Sullivan, Rodney Whiteley, Peter B O'Sullivan, Alexandra Korakaki, Argyro Kotsifaki, Panagiotis V Tsaklis, Athanasios Tsiokanos, and Giannis Giakas. Notions of "optimal" posture are loaded with meaning. perceptions of sitting posture among asymptomatic members of the community. *Musculoskeletal Science and Practice*, 51:102310, 2021. URL `https://doi.org/10.1016/j.msksp.2020.102310`.

Ilseok Lee, Sunghyun Sim, and Sangeun Jin. Hamstring stretching significantly changes the sitting biomechanics. *International Journal of Industrial Ergonomics*, 84:103163, 2021. URL `https://doi.org/10.1016/j.ergon.2021.103163`.

Sojeong Lee, Hwayeong Kang, and Gwanseob Shin. Head flexion angle while using a smartphone. *Ergonomics*, 58 (2):220–226, 2015. URL `https://doi.org/10.1080/00140139.2014.967311`.

Yoonjin Lee, Donghyun Beck, and Woojin Park. Human factors evaluation of an ambient display for real-time posture feedback to sedentary workers. *IEEE Access*, 8: 223405–223417, 2020. URL `https://doi.org/10.1109/ACCESS.2020.3044316`.

Herschel W Leibowitz, Charlotte L Shupert, and Robert B Post. The two modes of visual processing: Implications for spatial orientation. *NASA. Dryden Flight Research Center Peripheral Vision Horizon Display (PVHD)*, 1984.

James R Lewis and Jeff Sauro. Can i leave this one out?

the effect of dropping an item from the sus. *Journal of Usability Studies*, 13(1), 2017.

Paul P. Maglio and Christopher S. Campbell. Tradeoffs in displaying peripheral information. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '00, page 241–248, New York, NY, USA, 2000. Association for Computing Machinery. ISBN 1581132166. URL `https://doi.org/10.1145/332040.332438`.

Aristides Mairena, Carl Gutwin, and Andy Cockburn. Peripheral notifications in large displays: Effects of feature combination and task interference. In *Proceedings of the 2019 CHI conference on human factors in computing systems*, pages 1–12, 2019. URL `https://doi.org/10.1145/3290605.3300870`.

Leonardo Martins, Rui Lucena, João Belo, Marcelo Santos, Cláudia Quaresma, Adelaide P Jesus, and Pedro Vieira. Intelligent chair sensor: classification of sitting posture. In *Engineering Applications of Neural Networks: 14th International Conference, EANN 2013, Halkidiki, Greece, September 13-16, 2013 Proceedings, Part I 14*, pages 182–191. Springer, 2013. URL `https://doi.org/10.1007/978-3-642-41013-0_19`.

Richard E Mayer, Julie Heiser, and Steve Lonn. Cognitive constraints on multimedia learning: When presenting more material results in less understanding. *Journal of educational psychology*, 93(1):187, 2001. URL `https://doi.org/10.1037/0022-0663.93.1.187`.

Jan Meyer, Bert Arnrich, Johannes Schumm, and Gerhard Troster. Design and modeling of a textile pressure sensor for sitting posture classification. *IEEE Sensors Journal*, 10 (8):1391–1398, 2010. URL `https://doi.org/10.1109/JSEN.2009.2037330`.

Deedee A. Min, Yaejin Kim, Sung A. Jang, Keun Young Kim, Su-Eun Jung, and Ji-Hyun Lee. Pretty pelvis: A virtual pet application that breaks sedentary time by promoting gestural interaction. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '15, page 1259–1264, New York, NY, USA, 2015. Association for Computing

Machinery. ISBN 9781450331463. URL `https://doi.org/10.1145/2702613.2732807`.

Svetlana Mironcika, Annika Hupfeld, Joep Frens, Jessica Asjes, and Stephan Wensveen. Snap-snap t-shirt: Posture awareness through playful and somaesthetic experience. TEI '20, page 799–809, New York, NY, USA, 2020. Association for Computing Machinery. ISBN 9781450361071. URL `https://doi.org/10.1145/3374920.3375013`.

Bilge Mutlu, Andreas Krause, Jodi Forlizzi, Carlos Guestrin, and Jessica Hodgins. Robust, low-cost, non-intrusive sensing and recognition of seated postures. In *Proceedings of the 20th Annual ACM Symposium on User Interface Software and Technology*, UIST '07, page 149–158, New York, NY, USA, 2007. Association for Computing Machinery. ISBN 9781595936790. URL `https://doi.org/10.1145/1294211.1294237`.

G Jakus K Novak, Kristina Stojmenova, and J Sodnik. Assessment of cognitive load through biometric monitoring. *Society for Information Systems and Computer Networks: Ljubljana, Slovenia*, 2017.

Rita Orji and Karyn Moffatt. Persuasive technology for health and wellness: State-of-the-art and emerging trends. *Health informatics journal*, 24(1):66–91, 2018. URL `https://doi.org/10.1177/1460458216650979`.

Kieran O'Sullivan, Peter O'Sullivan, Leonard O'Sullivan, and Wim Dankaerts. What do physiotherapists consider to be the best sitting spinal posture? *Manual therapy*, 17 (5):432–437, 2012. URL `https://doi.org/10.1016/j.math.2012.04.007`.

Joo-hee Park, Sun-young Kang, Heon-seock Cynn, Hyeseon Jeon, et al. Effect of tactile feedback on trunk posture and emg activity in people with postural kyphosis during vdt work. *Physical Therapy Korea*, 23(3):48–56, 2016. URL `http://dx.doi.org/10.12674/ptk.2016.23.3.048`.

So Hyun Park. Kinematic analysis of the lower cervical spine in the protracted and retracted neck flexion positions. *Journal of Physical Therapy Science*, 27(1):135–137,

2015. URL `https://doi.org/10.1589/jpts.27.135`.

Amanda Parkes, Ivan Poupyrev, and Hiroshi Ishii. Designing kinetic interactions for organic user interfaces. *Communications of the ACM*, 51(6):58–65, 2008. URL `https://doi.org/10.1145/1349026.1349039`.

Anastasios Petropoulos, Dimitrios Sikeridis, and Theodore Antonakopoulos. Spomo: Imu-based real-time sitting posture monitoring. In *2017 IEEE 7th International Conference on Consumer Electronics-Berlin (ICCE-Berlin)*, pages 5–9. IEEE, 2017. URL `https://doi.org/10.1109/ICCE-Berlin.2017.8210574`.

Christopher Plaue and John Stasko. Animation in a peripheral display: distraction, appeal, and information conveyance in varying display configurations. In *Proceedings of graphics interface 2007*, pages 135–142, 2007. URL `https://doi.org/10.1145/1268517.1268541`.

Karen V Richards, Darren J Beales, Anne L Smith, Peter B O'Sullivan, and Leon M Straker. Is neck posture subgroup in late adolescence a risk factor for persistent neck pain in young adults? a prospective study. *Physical therapy*, 101(3), 2021. URL `https://doi.org/10.1093/ptj/pzab007`.

Silvia Rus, Andreas Braun, Florian Kirchbuchner, and Arjan Kuijper. E-textile capacitive electrodes: Fabric or thread: Designing an e-textile cushion for sitting posture detection. In *Proceedings of the 12th ACM International Conference on PErvasive Technologies Related to Assistive Environments*, PETRA '19, page 49–52, New York, NY, USA, 2019. Association for Computing Machinery. ISBN 9781450362320. URL `https://doi.org/10.1145/3316782.3316785`.

Steven W Savage, Lauren P Spano, and Alex R Bowers. The effects of age and cognitive load on peripheral-detection performance. *Journal of vision*, 19(1):15–15, 2019. URL `https://doi.org/10.1167%2F19.1.15`.

Hendrik Schmidt, Maxim Bashkuev, Marcel Dreischarf, Antonius Rohlmann, Georg Duda, Hans-Joachim Wilke, and Aboulfazl Shirazi-Adl. Computational biomechanics of a lumbar motion segment in pure and combined shear loads. *Journal of biomechanics*, 46(14):2513–2521, 2013. URL `https://doi.org/10.1016/j.jbiomech.2013.06.038`.

Gunnar Schmidtmann, Andrew J Logan, Graeme J Kennedy, Gael E Gordon, and Gunter Loffler. Distinct lower visual field preference for object shape. *Journal of Vision*, 15(5):18–18, 2015. URL `https://doi.org/10.1167/15.5.18`.

Ionut-Cristian Severin. Head posture monitor based on 3 imu sensors: Consideration toward healthcare application. In *2020 International Conference on e-Health and Bioengineering (EHB)*, pages 1–4. IEEE, 2020. URL `https://doi.org/10.1109/EHB50910.2020.9280106`.

Ben Shelton, Keith Nesbitt, Alexander Thorpe, and Ami Eidels. Assessing the cognitive load associated with ambient displays. *Personal and Ubiquitous Computing*, pages 1–20, 2022. URL `https://doi.org/10.1007/s00779-021-01662-w`.

Joon-Gi Shin, Eiji Onchi, Maria J Reyes, Junbong Song, Uichin Lee, Seung-Hee Lee, and Daniel Saakes. Slow robots for unobtrusive posture correction. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, pages 1–10, 2019. URL `https://doi.org/10.1145/3290605.3300843`.

Joon Gi Shin, Doheon Kim, Chaehan So, and Daniel Saakes. Body follows eye: Unobtrusive posture manipulation through a dynamic content position in virtual reality. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, CHI '20, page 1–14, New York, NY, USA, 2020. Association for Computing Machinery. ISBN 9781450367080. URL `https://doi.org/10.1145/3313831.3376794`.

Joongi Shin, Woohyeok Choi, Uichin Lee, and Daniel Saakes. Actuating a monitor for posture changes. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*, pages 1–6, 2018. URL `https://doi.org/10.1145/3170427.3188562`.

Stephanie Stockwell, Mike Trott, Mark Tully, Jae Shin, Yvonne Barnett, Laurie Butler, Daragh McDermott, Felipe Schuch, and Lee Smith. Changes in physical activity and sedentary behaviours from before to during the covid-19 pandemic lockdown: a systematic review. *BMJ open sport & exercise medicine*, 7(1):e000960, 2021. URL `https://doi.org/10.1136/bmjsem-2020-000960`.

Alan Stokes, Christopher Wickens, and Kirsten Kite. Display technology-human factors concepts. *NASA STI/Recon Technical Report A*, 90:32290, 1990. URL `https://doi.org/10.1016/0003-6870(91)90396-Y`.

Leon Straker, Rachel Skoss, Angus Burnett, and Robin Burgess-Limerick. Effect of visual display height on modelled upper and lower cervical gravitational moment, muscle capacity and relative strain. *Ergonomics*, 52 (2):204–221, 2009. URL `https://doi.org/10.1080/00140130802331609`.

Somayeh Tahernejad, Mohsen Razeghi, Mohammad Abdoli-Eramaki, Hossein Parsaei, Mozhgan Seif, and Alireza Choobineh. Recommended maximum holding time of common static sitting postures of office workers: Recommended maximum holding time of common sitting postures. *International Journal of Occupational Safety and Ergonomics*, pages 1–15, 06 2022. URL `https://doi.org/10.1080/10803548.2022.2085418`.

Meirav Taieb-Maimon, Julie Cwikel, Bracha Shapira, and Ido Orenstein. The effectiveness of a training method using self-modeling webcam photos for reducing musculoskeletal risk among office workers using computers. *Applied ergonomics*, 43(2):376–385, 2012. URL `https://doi.org/10.1016/j.apergo.2011.05.015`.

Yushi Takayama, Shun Ishii, Anna Yokokubo, and Guillaume Lopez. Detecting forward leaning posture using esense and developing a posture improvement promoting system. In *Adjunct Proceedings of the 2021 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2021 ACM International Symposium on Wearable Computers*, UbiComp '21, page 178–179, New York, NY, USA, 2021. Association for Computing Machinery. ISBN 9781450384612. URL `https://doi.org/10.1145/3460418.3479321`.

Hong Z Tan, Lynne A Slivovsky, and Alex Pentland. A sensing chair using pressure distribution sensors. *IEEE/ASME Transactions On Mechatronics*, 6(3):261–268, 2001. URL `https://doi.org/10.1109/3516.951364`.

Brett Taylor, Max Birk, Regan L Mandryk, and Zenja Ivkovic. Posture training with real-time visual feedback. In *CHI'13 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '13, pages 3135–3138. Association for Computing Machinery, 2013. ISBN 9781450319522. URL `https://doi.org/10.1145/2468356.2479629`.

Kian Sek Tee, Eugene Low, Wellesly Tony, Binti M K Safinaz, and Jaysuman B Pusppanthan. A posture monitoring system with imu for ophthalmologist while operating the slit lamp. *Indonesian Journal of Electrical Engineering and Computer Science*, 18(3):1262–1269, 2020. URL `http://doi.org/10.11591/ijeecs.v18.i3.pp1262-1269`.

Anna Torén. Muscle activity and range of motion during active trunk rotation in a sitting posture. *Applied Ergonomics*, 32(6):583–591, 2001. URL `https://doi.org/10.1016/s0003-6870(01)00040-0`.

Margarita Vergara and Álvaro Page. Relationship between comfort and back posture and mobility in sitting-posture. *Applied ergonomics*, 33(1):1–8, 2002. URL `https://doi.org/10.1016/s0003-6870(01)00056-4`.

Qi Wang. Designing posture monitoring garments to support rehabilitation. In *Proceedings of the TEI '16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction*, TEI '16, page 709–712, New York, NY, USA, 2016. Association for Computing Machinery. ISBN 9781450335829. URL `https://doi.org/10.1145/2839462.2854106`.

Zongyuan Wang and Brittany RL Duff. All loads are not equal: Distinct influences of perceptual load and cognitive load on peripheral ad processing. *Media Psychology*, 19(4):589–613, 2016. URL `https://doi.org/10.1080/15213269.2015.1108204`.

David Warnock, Marilyn McGee-Lennon, and Stephen Brewster. The role of modality in notification performance. In Pedro Campos, Nicholas Graham, Joaquim Jorge, Nuno Nunes, Philippe Palanque, and Marco Winckler, editors, *Human-Computer Interaction – INTERACT 2011*, pages 572–588, Berlin, Heidelberg, 2011. Springer Berlin Heidelberg. ISBN 978-3-642-23771-3. URL `https://doi.org/10.1007/978-3-642-23771-3_43`.

Christopher D Wickens, Emily K Muthard, Amy L Alexander, Patrick Van Olffen, and Elizabeth Podczerwinski. The influences of display highlighting and size and event eccentricity for aviation surveillance. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, volume 47, pages 149–153. SAGE Publications Sage CA: Los Angeles, CA, 2003. URL `https://doi.org/10.1177/154193120304700131`.

Christopher D Wickens, Justin G Hollands, Simon Banbury, and Raja Parasuraman. *Engineering psychology and human performance*. Psychology Press, 2015. ISBN 9781315665177. URL `https://doi.org/10.4324/9781315665177`.

Leonard J Williams. Peripheral target recognition and visual field narrowing in aviators and nonaviators. *The International Journal of Aviation Psychology*, 5(2):215–232, 1995. URL `https://doi.org/10.1207/s15327108ijap0502_6`.

Matthias Wölfel. Acceptance of dynamic feedback to poor sitting habits by anthropomorphic objects. In *Proceedings of the 11th EAI international conference on pervasive computing technologies for healthcare*, pages 307–314, 2017. URL `https://doi.org/10.1145/3154862.3154928`.

Lauren Womersley and Stephen May. Sitting posture of subjects with postural backache. *Journal of manipulative and physiological therapeutics*, 29(3):213–218, 2006. URL `https://doi.org/10.1016/j.jmpt.2006.01.002`.

Yu-Chian Wu, Te-Yen Wu, Paul Taele, Bryan Wang, Jun-You Liu, Pin-sung Ku, Po-En Lai, and Mike Y. Chen. Activeergo: Automatic and personalized ergonomics using self-actuating furniture. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, CHI '18, page 1–8, New York, NY, USA, 2018. Association for Computing Machinery. ISBN 9781450356206. URL `https://doi.org/10.1145/3173574.3174132`.

YM Xiao, ZM Wang, MZ Wang, and YJ Lan. The appraisal of reliability and validity of subjective workload assessment technique and nasa-task load index. *Zhonghua lao dong wei sheng zhi ye bing za zhi= Zhonghua laodong weisheng zhiyebing zazhi= Chinese journal of industrial hygiene and occupational diseases*, 23(3):178–181, 2005.

Ritsuko Yamada, Hiroya Kumamaru, Ei-ichiro Takebayashi, and Sei-ichi Yamada. Quantitative evaluation of poor posture as a key factor related to physical fatigue in vdt workers. *Ningen Dock International*, 7(1):32–37, 2020. URL `https://doi.org/10.11320/ningendockitn.7.1_32`.

Jun-Tian Zhang, Alison C Novak, Brenda Brouwer, and Qingguo Li. Concurrent validation of xsens mvn measurement of lower limb joint angular kinematics. *Physiological measurement*, 34(8):N63, 2013. URL `https://doi.org/10.1088/0967-3334/34/8/n63`.

Ying Zheng and John B Morrell. A vibrotactile feedback approach to posture guidance. In *2010 IEEE haptics symposium*, pages 351–358. IEEE, 2010. URL `https://doi.org/10.1109/HAPTIC.2010.5444633`.

Liuyang Zhou, Zhiguang Liu, Howard Leung, and Hubert PH Shum. Posture reconstruction using kinect with a probabilistic model. In *Proceedings of the 20th ACM Symposium on Virtual Reality Software and Technology*, pages 117–125, 2014. URL `https://doi.org/10.1145/2671015.2671021`.

Index

Typeset April 16, 2023