Aalen University

Master's degree program (M.Sc.) Vision Science and Business (Optometry) at the Hochschule Aalen (Aalen University)
Aalen, BW, Germany

in cooperation with the

New England College of Optometry
Boston, MA, USA

and the

College of Optometry at Pacific University Oregon
Forest Grove, OR, USA

OBJECTIVE AND SUBJECTIVE MEASUREMENTS OF VISUAL FATIGUE INDUCED BY SUSTAINED ONSCREEN READING

[OBJEKTIVE UND SUBJEKTIVE MESSUNG VON DURCH KONTINUIERLICHES BILDSCHIRMLESEN INDUZIERTER VISUELLER ERMÜDUNG]

Master thesis submitted to Aalen University in partial fulfillment of the requirements for the degree of Master of Science (M.Sc.) in Vision Science and Business (Optometry)

Martin D. Kündig

Supervised by
Prof. Yu-Chi Tai, MA, PhD
Vision Performance Institute (VPI) Pacific University Oregon, Forest Grove, USA
and
Prof. Dr. h.c. Dietmar Kümmel
Hochschule Aalen, Germany

September 2016

Preface

"Education is the kindling of a flame, not the filling of a vessel." Socrates

This thesis is dedicated to everyone lighting the fire, helping to keep it burn, protecting it against the wind, giving shelter from the rain, ensuring it doesn't cause damage, fan the flames, adding fuel to it, and those sitting at the fire enjoying love and friendship.

Thank you! I promise to pass the fire on and won't let it go out.

Acknowledgements

This thesis is based on the experimental apparatus and data of the Visual Fatigue Study of the Pacific University College of Optometry Vision Performance Institute (VPI), Forest Grove, Oregon, USA in which I collaborated as a visiting scholar. The idea and design for the Visual Fatigue Study was develop by principal investigator Yu-Chi Tai in collaboration with James Sheedy director of VPI and John Hayes. All experiments and associated methods were approved by the Pacific University Institutional Review Board (IRB) and followed the World Medical Association (WMA) Declaration of Helsinki – Ethical Principles for Medical Research Involving Human Subjects. The Visual Fatigue Study is supported by a research grant to Yu-Chi Tai and the VPI by the Advanced Reading Technologies Group of the Microsoft Corporation.

Data collection was carried out by various research assistants with background in either biology, vision science, or optometry. The data analysis in Chapter 4 and conclusions presented in Chapter 5 are my original work, with the occasional input of my supervisors and John Hayes who served as advising statistician. Chapter 1 is the result of literature research mainly carried out after my return to Switzerland.

An abstract as well as a poster of the work reported was presented at the 2016 annual meeting of the Association for Research in Vision and Ophthalmology (ARVO) in Seattle, WA, USA. Authors of the abstract are Martin D. Kündig, Yu-Chi Tai, John R. Hayes, and James E. Sheedy. Other than that, no part of the thesis has been previously published.

Declaration

I, Martin D. Kündig, assure that the present thesis entitled "Objective and Subjective Measurements of Visual Fatigue Induced by Sustained Onscreen Reading" is my original work issued by myself, and that all sources and external help is indicated.

Sentences or parts of sentences quoted literally are marked as quotations; and reference to all indirect quotations is given.

The thesis in this form or in any other form has not been submitted to any other examination board.

Kaiseraugst, November 17, 2016

_____

Martin D. Kündig

Abstract

Purpose: Prolonged near-distance viewing has long been regarded as the main source of visual fatigue; however, the physiological causes remain unclear. Using within-subject design, this study examined the changes of accommodative, vergence, and pupillary functions over a long reading time (≈8 hours). We hypothesized that, with increased reading time, visual fatigue would be increased and the oculomotor system would be affected.

Methods: Thirty-four subjects (normal vision, no history of eyestrain) read from a computer screen at 55 cm for 5 blocks (50–60 min each). Real-time measurements of accommodation (Spherical Equivalent Refraction = SER), vergence (through eye positions recording), and pupil size were recorded. Clinical tests were conducted off-screen at baseline and after each block, including accommodative amplitude, accommodative facility, fusional vergence reserve (base-in break, base-in recovery, base-out break, base-out recovery) and vergence facility. A survey with 27 questions was administered at the same time. The total test time was about 8 hours. Mixed model ANOVAs were used to analyze the effect of time (block) on the objective responses with baseline measurement as covariant. Subjective symptom ratings were categorized into four latent factors using factor analysis before further analysis.

Results: Significant effect of time was observed on real-time SER ($p = .007$), accommodation facility ($p = .003$), base-in break ($p < .001$), base-in recovery ($p = .036$), and vergence facility ($p = .001$). Overall, negative fusional vergence ranges, accommodation facility, and SER decreased (i.e., accommodative lag increased), while vergence facility increased as reading continued. No significant effect was observed on other objective measurements. Subjective symptoms were significantly higher ($p < .001$) in later blocks for factors of Mental & Physical

Fatigue, Eye Discomfort and Text Perception while they were significantly lower (p = .029) for Display Setting.

Conclusions: Previous research has found increased accommodative lag and decreased accommodative facility associated with accommodative insufficiency, which contributes to visual fatigue. The current study found increments in subjective symptoms and changes in objective measurements of accommodative lag (increased) and accommodative facility (decreased) over time, consistent with these reports. However, in this study subjects with normal vision reported moderate symptoms when reading with frequent breaks, suggesting reserved capacity even after 7–8 hours of testing. To determine if this leads to lack of significant effect on the pupillary and vergence system, other than the negative fusional vergence reserve (base-in break and recovery) and vergence facility, further studies are needed to investigate how more severe visual fatigue may affect the ocular system.

Zusammenfassung

Titel: Objektive und subjektive Messung von durch kontinuierliches Bildschirmlesen induzierter visueller Ermüdung

Zweck: Ausgedehntes Sehen im Nahbereich wird seit Langem als Hauptgrund für visuelle Ermüdung (visual fatigue) betrachtet, jedoch sind die physiologischen Ursachen nach wie vor unklar. Mithilfe eines Innersubjektdesigns wurden in dieser Studie Veränderungen der Akkommodations-, Vergenz- und Pupillenfunktionen über eine lange Lesedauer (≈8 Stunden) beobachtet. Wir stellten die Hypothese auf, dass mit zunehmender Lesedauer die visuelle Ermüdung zunimmt, was die Okulomotorik beeinflusst.

Methode: Vierunddreißig visuell unauffällige Probanden lasen auf einem Bildschirm in 55 cm Entfernung während 5 Blöcken von je 50 bis 60 Minuten. Die Akkommodation (sphärisches Äquivalent = SER), die Vergenz (via Aufzeichnung der Augenpositionen) und die Pupillengröße wurden kontinuierlich in Echtzeit gemessen. Zusätzlich wurden mittels klinischen Tests nach jedem Leseblock sowie vor dem ersten Lesen die Akkommodationsbreite, Akkommodationsflexibilität, fusionalen Vergenzreserven (Basis-Innen-Break und -Recovery sowie Basis-Außen-Break und -Recovery) und Vergenzflexibilität gemessen. Ein 27 Fragen umfassender Fragebogen zur Ermittlung von subjektiven Symptomen wurde zeitgleich abgefragt. Die totale Testdauer pro Proband betrug acht Stunden. Mixed-model ANOVAs wurden verwendet, um den Effekt der Lesedauer (Block) auf die Variablen zu analysieren. Dabei wurden die Ausgangsmessungen als Kovarianzen verwendet. Die Bewertungen der subjektiven Symptome wurden vor der weiteren Analyse mittels Faktoranalyse in vier Faktoren unterteilt.

Resultate: Signifikante Effekte der Lesedauer auf das Echtzeit-SER ($p = .007$), die Akkommodationsflexibilität ($p = .003$), das Basis-Innen-Break ($p < .001$), das Basis-Innen-Recovery ($p = .036$) und die Vergenzflexibilität ($p = .001$) wurden gefunden. Gesamthaft nahmen die negativen fusionalen Vergenzreserven, die Akkommodationsflexibilität und das SER mit zunehmender Lesedauer ab (entspricht einer Zunahme des Akkommodationslag), während die Vergenzflexibilität zunahm. Es konnte kein signifikanter Effekt auf die weiteren objektiv gemessenen Variablen gefunden werden. Die subjektiven Symptome der Faktoren mentale und physische Ermüdung (Mental and Physical Fatigue), Augenunbequemlichkeit (Eye Discomfort) und Textwahrnehmung (Text Perception) wurden in späteren Blöcken signifikant höher ($p < .001$) bewertet, die Unzufriedenheit mit den Bildschirmeinstellungen (Display Setting) war gegen Ende der Untersuchung signifikant tiefer ($p = .029$).

Fazit: Frühere Forschungen haben ein erhöhtes Akkommodationslag sowie eine reduzierte Akkommodationsflexibilität mit Akkommodationsinsuffizienz, die zur visuellen Ermüdung beiträgt, in Verbindung gebracht. Die vorliegende Studie hat einen Anstieg von subjektiven Symptomen sowie Änderungen im Akkommodationslag (Zunahme) und in der Akkommodationsflexibilität (Abnahme) über eine längere Lesedauer im Einklang mit diesen früheren Berichten gefunden. Indes haben in unserer Studie Subjekte mit normalem, unauffälligem visuellem System beim Lesen mit regelmäßigen Pausen lediglich moderate Symptome angegeben. Was auf ausreichende Reserven des visuellen Systems selbst nach 7 bis 8 Stunden des Testens schließen lässt. Um festzustellen, ob das Fehlen von signifikanten Effekten auf die Pupillenreaktion und das Vergenzsystem (mit wenigen Ausnahmen) diesem Umstand geschuldet ist, sind weitere Studien nötig, die den Einfluss von schwerwiegender visueller Ermüdung auf die Okulomotorik und das visuelle System untersuchen.

Table of Contents

1. Introduction

Visual fatigue is a pervasive and complex phenomenon affecting many people. As will be discussed in more detail in Chapter 2.1.3., studies found up to 93% of the general population being affected[1] and its economic impacted is thought to expand to 2 billion US$.[2] Visual fatigue has been found to have a detrimental effect on various visual functions such as eye movements, reading behavior, pupil size, accommodation, coordination of the two eyes, and dry eye.[3–5] For more details also see Chapter 2.

Prolonged near-distance viewing has long been regarded as main source of visual fatigue[6]; however, the physiological causes remain unclear. While various visual functions have been monitored during the visual fatigue study (see Chapter 3.2. for a list), this thesis focuses on functions related to the oculomotor near-response triad reflex as described in Chapter 2.2.

1.1. Hypothesis and Purpose

We hypothesized that, (1) with increased reading time, visual fatigue would be increased, and (2) the oculomotor system would be affected. Furthermore, with the help of objective and subjective measurements, we wanted to determine if visually fatigued individuals are suffering more from blurred or double vision.

We have been interested in the changes that occur during a regular computer working day. Therefore, we continuously monitored visual functions of normal individuals for about 8 hours.

To our knowledge, only one previous study continually recorded visual functions performing a multiple-hour near-vision task.[7] However, since 1947 recording technologies as well as demands to the visual system have increased tremendously.

The findings of this study will help to better understand the pathophysiology of visual fatigue and, by doing so, help the clinicians when dealing with visually fatigued subjects. Furthermore, results of this study might provide manufacturers of computer display technology with hints on how to improve the design of computer displays to optimize viewers' comfort and reading performance in daily computer-based near-vision activities.