A Survey of Digital Eye Strain in Gaze-Based Interactive Systems

Teresa Hirzle
Institute of Media Informatics
Ulm University, Germany
teresa.hirzle@uni-ulm.de

Maurice Cordts
Institute of Media Informatics
Ulm University, Germany
maurice.cordts@uni-ulm.de

Enrico Rukzio
Institute of Media Informatics
Ulm University, Germany
enrico.rukzio@uni-ulm.de

Andreas Bulling
Institute for Visualisation and Interactive Systems
University of Stuttgart, Germany
andreas.bulling@vis.uni-stuttgart.de

ABSTRACT

Display-based interfaces pose high demands on users' eyes that can cause severe vision and eye problems, also known as digital eye strain (DES). Although these problems can become even more severe if the eyes are actively used for interaction, prior work on gaze-based interfaces has largely neglected these risks. We offer the first comprehensive account of DES in gaze-based interactive systems that is specifically geared to gaze interaction designers. Through an extensive survey of more than 400 papers published over the last 46 years, we first discuss the current role of DES in interactive systems. One key finding is that DES is only rarely considered when evaluating novel gaze interfaces and neglected in discussions of usability. We identify the main causes and solutions to DES and derive recommendations for interaction designers on how to guide future research on evaluating and alleviating DES.

CCS CONCEPTS

• **Human-centered computing → Interaction techniques**; • **Applied computing → Consumer health**.

KEYWORDS

Eye-based Interaction, Gaze Interaction, Digital Eye Strain, Visual Discomfort, Interactive Systems

ACM Reference Format:
Teresa Hirzle, Maurice Cordts, Enrico Rukzio, and Andreas Bulling. 2020. A Survey of Digital Eye Strain in Gaze-Based Interactive Systems. In *Symposium on Eye Tracking Research and Applications (ETRA '20 Full Papers), June 2–5, 2020, Stuttgart, Germany.* ACM, New York, NY, USA, 12 pages. https://doi.org/10.1145/3379155.3391313

1 INTRODUCTION

Digital eye strain (DES) has been observed in computer users since the first screen-based devices were introduced [Blehm et al. 2005]. Traditionally, DES has been investigated with computer monitors, often as part of work place ergonomics [Ong et al. 1988]. The shift from using computers exclusively at work towards using them pervasively in everyday life has turned DES into an omnipresent problem with up to 90% of computer users being affected [Rosenfield 2011]. When extrapolating this into a future where computerized eyewear will additionally be used [Bulling and Kunze 2016], it is conceivable that DES becomes an even more serious health problem.

The effects of DES negatively impact users' general well-being and quality of life [Miljanović et al. 2007] and may lead to vision problems, such as lags in accommodation [Rosenfield 2011; Tosha et al. 2009] and vergence [Blehm et al. 2005] responses or the dry eye syndrome [Miljanović et al. 2007]. Gaze-based interfaces increase these problems as they add an active function to the eye's primary function as a perceptual organ. Recent work has shown that gaze input (e.g., dwell time interaction) can lead to an additional demand on the eyes and thus further enhance DES [Putze et al. 2016; Rajanna 2016; Rajanna and Hammond 2016]. Despite the severe health problems posed by DES, which can be expected to become even more serious in the future, prior research on gaze-based interfaces has largely neglected these risks.

We offer the first comprehensive account of the problems of DES. Through an extensive survey of more than 400 papers published over the last 46 years, we first provide an overview of objective and subjective assessment methods of DES and discuss how they can be applied by non-experts. We then summarize causes and point out which ones stem from passively observing digital content and which ones result from active eye-based input. Finally, we present current solutions to DES and give an overview which symptoms they address and which ones are currently neglected.

One key finding is that despite the negative impact of DES on users' health, solutions to alleviate or avoid the symptoms are rare in that they mainly address causes that stem from the interaction device, but only few that stem from gaze-based techniques. Also, eye strain is only rarely considered when evaluating novel eye-based interfaces and little attention is paid to it in discussions of usability of gaze interaction techniques. Additionally, the amount of different measurement techniques combined with inconsistent

---

ETRA '20 Full Papers, June 2–5, 2020, Stuttgart, Germany

ACM ISBN 978-1-4503-7133-9/20/06…$15.00
https://doi.org/10.1145/3379155.3391313

Table 1: Keywords that were used for the online search.

gaze interaction-related	gaze-based, gaze interaction, eye-based, human-computer interaction, interactive system
DES-related	computer vision syndrome, eye fatigue, eye strain, visual discomfort, visual fatigue, eye health

terminology have made it difficult to identify suitable assessment methods, as well as solutions. Based on our findings, we derive recommendations on how future research should evaluate gaze interaction techniques and develop solutions to alleviate it.

The specific contributions of our work are three-fold. First, we present a comprehensive overview of objective and subjective assessment methods of DES and cluster its causes into those *passively* caused by looking at displays and *actively* caused by explicit eye-based interaction. Second, we present current approaches that aim to alleviate DES in interactive systems. Finally, we share insights on challenges that have to be overcome and give recommendations that could guide future research to develop potential solutions.

2 METHOD

The goal of our literature survey is to gain knowledge on how the gaze interaction community currently deals with digital eye strain. More specifically, we aim to identify causes, assessment methods, and approaches to alleviate DES. To address these goals we conducted a comprehensive literature survey based on two sets of keywords (see Table 1). Given that this paper is specifically geared to the gaze interaction community, we defined one set of *gaze interaction-related* keywords in addition to one of *DES-related* keywords. We then conducted an online search of the two scientific databases that include the most relevant conferences and journals on interactive systems (ACM Digital Library[1] and IEEE Xplore[2]) with both sets of keywords in a three-step process loosely based on the steps suggested by the PRISMA guidelines [Moher et al. 2009].

We started with identifying assessment methods and causes. To this end, we first searched in full text and meta data (abstract, title, keywords) of named data bases (limited to conference and journal publications) using the *DES-related* terms. We found 1246 (499 IEEE, 747 ACM) papers, the oldest of which was published in 1919 [Stickney 1919]. In order to identify possible solutions, we further limited this set by filtering the papers using the *interaction-related* keywords, which resulted in 465 papers in a time period of 1973 to 2019. By skimming through the titles of the remaining 781 papers, we added 8 papers to the set that seemed important due to their title, e.g., [Dementyev and Holz 2017; Tong Boon Tang and Noor 2015], leaving us with a set of 473 papers.

In a second step two of the authors identified the section(s) in which the keywords were mentioned. This allowed us to exclude papers that did not measure or focus on eye strain but mentioned it as one of many terms, e.g., in the related work section, which left us with 137 papers. For these, two of the authors read through abstract, introduction, and conclusion, and added a brief summary of these sections to two columns (topic and result) in a large spreadsheet.

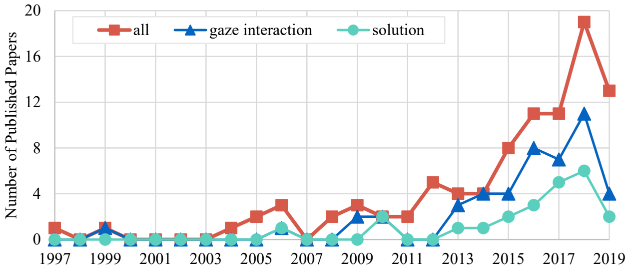

Figure 1: Our survey includes papers that were published in the last 22 years. Until 2012, solutions to DES were rare. Although since then more solutions were proposed, they are still far from being fully integrated in interactive systems.

Finally, we classified the remaining papers into *assessing DES*, identifying *causes or influences*, presenting a *solution*, or providing qualitative insights. Although in some papers there was an overlap of categories, we classified papers into only one category, i.e., the one they contributed most to in our opinion.

We considered a paper relevant for our survey when it (1) presented or reported on assessment methods for DES (22), (2) identified a cause of DES (17), (3) presented a solution approach to avoid or alleviate DES (30), or (4) presented a gaze interaction method or qualitative feedback on DES in a user study although not explicitly focusing on the measurement of DES (23). A paper was classified as assessment-based if it presented insights on a study in which DES was assessed, with one exception [Park and Mun 2015] that presented an overview of assessment methods that affect the visual system. A paper was identified as causes-related if the authors reported on a cause that influences eye strain, e.g., by conducting a comparative study on several influence factors. Of the papers that were classified as solution-related (30), 21 were explicitly framed by the authors as combating a DES-related problem, like the vergence-accommodation conflict or close viewing distances. The other 9 papers were identified as solution-related by the reviewing authors, for instance, when they presented a technique that reduced eye strain without framing it explicitly as solution. The final set in this survey consists of 92 papers (see Figure 1). 47 of these were in some form related to gaze interaction (according to the continuum of eye tracking applications proposed in [Majaranta and Bulling 2014]). In the other 45 papers causes and influences of general interaction devices and techniques on DES were discussed.

We also identified several types of target devices (in some cases more than one in one paper): the majority of papers (55) had conventional displays as target device (including distant and tabletop displays). Other device types were HMDs (20), 3D displays and stereoscopic displays (9), small displays like smartphones and smart watches (5), smart glasses (3), driving simulators (2), projection systems (1), and 1 paper focused on eye trackers only.

Since this paper's main target audience are gaze interaction designers, our set of papers is biased towards interactive systems. This might have lead to relevant work from other communities being excluded, because we did not focus our search on medical or psychological venues. The medical papers that are cited in this work were found based on the discussed set of papers that referenced these medical ones.

---

[1] https://dl.acm.org/
[2] https://ieeexplore.ieee.org/

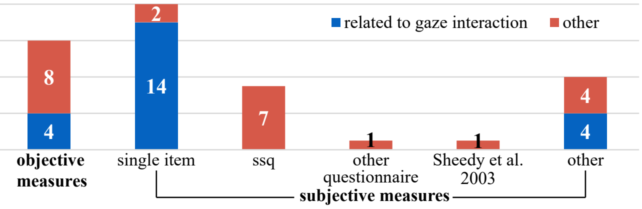

Figure 2: The distribution of papers is shown in which some form of DES assessment was used, divided into objective and subjective measures. In total they account for 45 of the surveyed papers, i.e., 47 did not assess DES.

3 ASSESSMENT METHODS FOR DES

Optometry experts proposed measures, mostly based on special medical devices, such as optometers or autorefractors to assess DES-related ocular symptoms and visual functions with high accuracy [Rosenfield 2011]. These measures require the expertise of an optometrist and are most often not compatible with the use of mobile display-based devices due to the size of the instruments.

Using the papers included in our survey as a basis, we investigated commonly used assessments methods for DES in interactive systems. Hereby, we divided these methods into **objective** [Billones et al. 2018; Park and Mun 2015; Wang et al. 2018] and **subjective** [del Mar Seguí et al. 2015; Sheedy et al. 2003] ones. Objective measures provide precise results on visual functions [Rosenfield 2011], but they can be difficult to integrate into user interfaces and some require special hardware or optometrist expertise. In contrast, subjective measures rely on user self-reporting and are therefore easier to integrate into the evaluation process, given that they do not require special hardware or software. Of the 45 papers in which DES was measured, in 12 objective measures were used and 33 subjective measures (see Figure 2 for details).

In the literature, attempts were made to relate causes and symptoms to each other. This is challenging, because there exists no unique link, but rather a n-to-n relation. Suggestions were made to group symptoms into *external* and *internal* ones [Sheedy et al. 2003; Zeri and Livi 2015], and into whether they disturb visual processing or result from the disturbance [Kennedy et al. 1993]. We integrated these findings into the definition of the following categories of symptoms. *External* symptoms refer to symptoms that can be localised on the surface of the eyes and include burning, irritation, and tearing. *Internal* ones are perceived internally and cannot be located on a specific area on the eye, but rather behind the eye. They include strain, ache, headache, double and blurred vision. In literature it is not agreed upon, whether *dry eye* belongs to external or internal symptoms. Therefore, we consider this as extra case.

3.1 Objective Assessment

As pointed out by Park and Mun, there are various physiological indicators that are influenced by DES and that can be measured using optometry methods [Park and Mun 2015]. Given that we are interested in solutions that are applicable for a wide range of researchers and practitioners, and that therefore do not require special hardware or expertise, we will focus on ocular metrics that can be obtained using an off-the-shelf eye tracker (see Table 2). Eye tracking can be easily integrated into devices and it has been shown that it can successfully be used to assess eye strain in interactive systems [Ishimaru et al. 2015; Wang et al. 2018].

Table 2: Overview of the objective assessment methods covered in this survey and their significance. All of these can be measured using an eye tracker.

Significance	Measure	Symptom	Source
decrease of	number of fixations	eye strain	[Wang et al. 2018]
increase of	fixation duration		[Wang et al. 2018]
decrease of	fixation accuracy		[Vasiljevas et al. 2016]
increase of	number of insignificant saccades	eye strain, general fatigue	[Billones et al. 2018] [Wang et al. 2018]
increase of	saccade length		[Bahill and Stark 1975]
decrease of	blink rate	dry eye	[Patel et al. 1991; Schlote et al. 2004]
increase of	incomplete blinks		[Portello et al. 2013]
decrease of	pupil size	eye strain	[Hoffman et al. 2008]
	adaptation time	* *caused by VA conflict*	[Shibata et al. 2011]

3.1.1 Fixation Metrics.

3.1.1 Fixation Metrics. During fixations, gaze (foveal vision) is held stable for 200-600 ms to perceive visual information [Majaranta and Bulling 2014]. The duration of fixations can be related to processing times in the brain and prolonged fixation duration was found to be an indicator for eye strain [Vasiljevas et al. 2016; Wang et al. 2018]. Naturally, this can also be measured by a decrease in the number of fixations.

3.1.2 Saccade Metrics. Saccades are quick (10-100ms) ballistic jumps of the eyes that typically occur between two fixations [Duchowski 2007]. Length and velocity of saccades were both linked to general fatigue [Bahill and Stark 1975]. Wang et al. further found that saccade length increased with eye strain [Wang et al. 2018], which suggests that fatiguing the saccadic eye movement system is closely linked to eye strain. This is also assumed by Kurzhals et al., who reduced saccade length in order to decrease eye strain [Kurzhals et al. 2017]. Increasing eye strain also leads to more insignificant saccades, i.e., saccades fail to be completed [Bahill and Stark 1975] or are carried out without being directed to the desired object of attention [Wang et al. 2018].

3.1.3 Blink Metrics. The average blink rate is at about 10-15 blinks per minute [Blehm et al. 2005]. Several works showed that prolonged screen time reduces blink rate and causes dry eye syndrome [Crnovrsanin et al. 2014; Patel et al. 1991; Portello et al. 2013; Schlote et al. 2004]. In addition to blink rate, the percentage of incomplete blinks (eye closures) increases with eye strain [Portello et al. 2013].

3.1.4 Pupil Diameter. Pupillary constriction and accommodation are closely coupled. They both respond to oculomotor depth cues and thus control how light is focused on the fovea defining the depth-of-focus [Reichelt et al. 2010]. Especially in artificial stereoscopic viewing conditions, where vergence and accommodation responses are decoupled, literature suggests that pupil responses are increasingly evoked to compensate for a lack of accommodative responses [Omori et al. 2011]. The constant contraction of the ciliary muscles that indirectly control pupil diameter might thus significantly contribute to eye strain.

3.2 Subjective Assessment

The detail and accuracy of subjective assessment methods vary significantly. A number of questionnaires for subjective assessment of DES were proposed in literature, as well as single item questions on different measurement scales (see Table 3). Some questionnaires cover up to 16 different symptoms of eye strain (e.g., the visual strain questionnaire [Howarth and Istance 1985]).

Overall 33 of the collected papers assessed eye strain using subjective methods. Although a variety of questionnaires exist, 16 of these works used single item questions on *eye fatigue*, *eye strain*, or *eye tiredness*, assessing a general idea of eye strain, but not specific symptoms (i.e., Likert scales [Ashtiani and MacKenzie 2010; Koh et al. 2009; Morimoto and Amir 2010; Nayyar et al. 2017; Pfeil et al. 2018; Pfeuffer et al. 2016; Rempel et al. 2009], Visual Analog Scales [Carter et al. 2015], or other semantic differential scales [Majaranta et al. 2009; Newn et al. 2016; Qian and Teather 2017; Rajanna and Hammond 2018; Seuntiens et al. 2006]).

Overall we found a close relation of eye strain to general fatigue and drowsiness [Ishrat and Abrol 2017; Nayak et al. 2012], simulator sickness [Häkkinen et al. 2006; Zhang et al. 2019a], and ergonomic posture [Kronenberg and Kuflik 2019]. Especially the simulator sickness questionnaire (SSQ) is important to name here, given that its oculomotor sub scale is used frequently for assessing eye strain in augmented or virtual reality (VR) settings [Kennedy et al. 1993]. The oculomotor sub scale (or oculomotor factor) can be divided into two factors, the first one includes *blurred vision* and *difficulty focusing* and displays disturbance of visual processing. The second one refers to the symptoms caused by that, and are *headache*, *eyestrain*, and *fatigue*. Ergonomic effects mostly refer to neck, back, and shoulder pain.

4 CAUSES

DES is a multifactorial problem that has various causes from different origins [Collier and Rosenfield 2011; Rosenfield 2011]. We divide causes into **passive** that stem from looking at the device and **active** that originate from explicit gaze interaction.

4.1 Passive Causes

Passive causes are device-based factors that stem from simply looking at a device. The three main passive causes we identified are the *close viewing distance* to display-based devices [Min et al. 2019; Sheedy et al. 2003], *display and user interface properties* [Rosenfield 2016], and the *vergence-accommodation (VA) conflict* that occurs in stereoscopic displays [Hoffman et al. 2008; Vienne et al. 2014].

4.1.1 *Close Viewing Distance.*

Close viewing distances, especially on mobile devices, cause a high demand of vergence and accommodation responses, resulting in a tension of the extraocular eye muscles, as well as the ciliary and pupillary muscles [Dillon and Emurian 1996; Ho et al. 2015] causing mainly internal DES factors, especially headache [Sheedy et al. 2003]. This intensified near-vision behaviour is unnatural, because the eyes evolved to mainly converge and accommodate to farther distances, at which the eye muscles are relaxed [Davson 1990].

4.1.2 *Display and User Interface Properties.*

Screen properties and poorly designed user interface elements additionally increase demands on users' eyes. Screen properties include primarily glare, flickering, color combinations, and too small interactive elements. Such properties can cause eye strain (mainly the external factors irritation and burning, and dry eye) by evoking increased muscle tension (e.g., in the ciliary muscles that control pupil diameter) [Sheedy et al. 2003]. One example for this are different polarization types of displays. Zhang et al. found that eye strain occurs less with circularly polarized light displays than with linearly polarized ones [Zhang et al. 2017]. Also, illumination [Kim et al. 2019; Wesson et al. 2012] and movement in peripheral vision have a negative influence [Takada et al. 2015].

Another strong influence on eye strain in computer interfaces is the use of color [Wright et al. 1997]. Chen and Huang investigated the influence of color values on the performance in gaze-based user interfaces [Chen and Huang 2018]. They found increased eye strain for higher red, green, and blue color values. They also found that high chroma values for green and blue did result in increased eye strain over low chroma values. Azuma and Koike observed that some users reported eye fatigue during the usage of color shift filters that divided the image into three color layers (cyan, magenta, and yellow) for guiding users' gaze to regions of interest [Azuma and Koike 2018]. Seuntiens et al. found higher eye strain values for higher compression values and a greater camera-base distance for stereoscopic JPEG images [Seuntiens et al. 2006].

Other factors of user interface elements that are known to increase eye strain are high contrast stimuli [Nakarada-Kordic and Lobb 2005; Shiwei Cheng 2015] and small text, for instance on smartwatches [Hansen et al. 2015], displays [Endert et al. 2012], or in VR [Gizatdinova et al. 2018].

4.1.3 *Vergence-Accommodation Conflict.*

The VA conflict is caused by a mismatch of oculomotor depth cues. While stereoscopic displays provide visual depth cues to invoke vergence (binocular disparity), most fail to display content on various focal planes and therefore fail to correctly invoke accommodation responses. Whereas in the real world these cues are tightly coupled, they are decoupled in most stereoscopic displays. It is known that the VA conflict [Kim et al. 2014; Souchet et al. 2018] and in general stereoscopic displays [Obrist et al. 2011] cause eye strain. Frequent symptoms are headache, blurred and double vision [Hoffman et al. 2008; Vienne et al. 2014], which we categorized as internal symptoms. Additionally, the VA conflict can even cause changes in ocular responses, e.g., in accommodation responses [Szpak et al. 2019].

4.2 Active Causes

Active causes stem from using the eyes actively to perform an input event in gaze-based interfaces. Gaze-based interaction techniques, especially gaze-only techniques, add an active input channel to the eyes' functionality of being passive observers [Zhai et al. 1999]. This generates additional and to some extent unnatural gaze behavior [Biswas and Langdon 2013]. For instance, multiple gaze commands [Ratsamee et al. 2015] or frequently switching between gaze interaction techniques [Mohan et al. 2018] can cause eye strain. We identified two active causes: *prolonged fixation duration* and *large number of long saccades*. Prolonged fixation duration may occur when using the eyes as pointing and selecting mechanism, enforcing them to fixate on a target longer than naturally occurring (e.g., dwell time selection). Further, long saccades produce fatigue [Bahill and Stark 1975]. Especially when used for prolonged periods they produce more eye strain than short saccades [Billones et al.

Table 3: Overview of the subjective assessment methods covered in this survey. These include questionnaires that assess several symptoms of DES, as well as single symptoms only, measured on different scales (e.g., Likert, Visual Analog Scales (VAS))

Questionnaire	Items	Scale
VSQ [Howarth and Istance 1985]	(a) tiredness of the eyes, (b) soreness or aching of the eyes, (c) soreness or irritation of the eyelids, (d) watering of the eyes, (e) dryness of the eyes, (f) a sensation of hot or 'burning' eyes, (g) a feeling of 'sand in the eyes'	1 (no discomfort) 5 (very bad discomfort)
SSQ (O) [Kennedy et al. 1993]	blurred vision, difficulty focusing	none, slight, moderate, severe
	headache, eye strain, fatigue	
[Zeri and Livi 2015]	external (eye burning, eye ache, eye strain, eye irritation, tearing) internal (blur, double vision, headache, dizziness, nausea) dryness	1 (nothing) 5 (very much)
[Sheedy et al. 2003]	external (burning, irritation, tearing, dryness) internal (ache, strain, headache, double vision, blur)	VAS
single item	eye strain, eye fatigue, eye tiredness	Likert scale, VAS, other

2018; Morimoto and Amir 2010]. While there are some eye-based techniques that can be assigned to mainly one of the two causes (e.g., calibration procedures on prolonged fixation duration [Blignaut 2013]), most gaze interaction techniques we found result in a combination of both. Furthermore, it is difficult to extract the influence of active causes, as they are usually investigated with device types that also cause symptoms. We argue that active causes, since they generate significant additional eye movement, in particular put strain to the extraocular muscles, and thus mainly contribute to internal symptoms. We derive this from similar causes in close viewing distances, since we did not find relations of active causes and explicit symptoms in the literature. In the following, we will discuss two main gaze interaction areas and how they affect eye strain.

4.2.1 Point, Select, Control. The eyes naturally indicate a person's overt attention that can be leveraged for gaze-based pointing, selection, and control. A common eye-only selection technique is the dwell time technique. Here, a user's gaze point is fixated for a predefined set of time on an interactive element in order to select it. Carter et al.'s work indicates that eye strain occurs when using gaze for selection independently of visual feedback [Carter et al. 2015]. The authors compared two versions of gaze and gesture interaction on a remote display. Both techniques induced eye strain, which indicates that using gaze for selecting targets strains the eyes with and without visual feedback. Pfeuffer et al. compared three interaction strategies that combine gaze, pen, and touch input [Pfeuffer et al. 2016]. They found equivalently high eye strain values for all techniques ($M = 4.2/5$), independently whether gaze was used for explicit interaction or not. Hild et al. found similar results for the combination of gaze and manual pointing [Hild et al. 2014, 2016]. Their results indicate that moving targets causes a medium value of eye strain independently of the combination of both modalities.

In contrast, Li et al., who combined gaze with touch input, found less eye strain when the eyes were being used solely for pointing in contrast to being used as a pointing and selection mechanism [Li et al. 2019]. Similarly, Rajanna and Hammond found that gaze input leads to higher eye strain values than touch and mouse input [Rajanna and Hammond 2018]. These findings are further supported by Qian and Teather, who reported increased eye fatigue values for an eye-only interaction technique compared to eye and head or head-only interaction [Qian and Teather 2017].

4.2.2 Gaze Typing. Text entry systems have a long history in eye-based interaction [Chakraborty et al. 2014; Majaranta et al. 2009; Vasiljevas et al. 2016]. A specific challenge is to create a mechanism that allows users to interact quickly without being prone to the Midas Touch effect and eye strain. Nayyar et al. proposed an adaptive dwell time selection technique that dynamically updates the dwell time for each selection based on the previous selection [Nayyar et al. 2017]. Results suggest, albeit not significant, that eye fatigue was lowest with an adaptive dwell time technique. Ashtiani and MacKenzie presented a blink-based text entry system and found that the level of eye strain could be reduced by increasing the accuracy of blink detection [Ashtiani and MacKenzie 2010]. Morimoto et al. considered eye strain in the design of gaze typing techniques in that they ensured to produce short saccades, since they produce less strain when used for prolonged periods [Morimoto et al. 2018]. Only 16% of their users stated that the system caused higher than average strain levels. Chakraborty et al. developed a text entry system that produced less eye strain than a dwell-based system by trading off prolonged fixation times with a larger number of saccades [Chakraborty et al. 2014]. When first gazing at a letter it gets activated and only selected if the user chooses to move their gaze outside and back inside the active area. This approach reduced eye strain, suggesting that long fixation times have a stronger impact on eye strain than the number of saccades.

5 SOLUTIONS

The vast majority of solutions that we found addressed passive causes. Only few approaches presented alternatives to explicit interaction strategies that pose additional demands on the eyes. In the following we group solution approaches around the presented causes after giving a short overview of general eye strain reduction.

5.1 General Eye Strain

Eye strain and ergonomic posture are related in that they both result from prolonged screen time. Chen et al. presented a framework to ensure an ergonomic posture during computer work while preserving productivity by personalizing notifications [Chen et al. 2012]. Kronenberg and Kuflik built a prototypical implementation of a self-adjusting computer screen that adapts the screen's orientation to the user's posture in order to ensure a healthy ergonomic posture [Kronenberg and Kuflik 2019].

5.2 Viewing Distance

Viewing distance is important for stationary, as well as mobile displays, since for both users tend to move too close to the screen. A healthy viewing behavior is meant to be kept when users focus at something 20 feet away every 20 minutes for 20 seconds (20-20-20 rule). Few systems were proposed that help users to follow this rule (e.g., [Jumpamule and Thapkun 2018]). Min et al. proposed glasses that observe users' gaze behavior while looking at a screen [Min et al. 2019]. By providing real-time feedback of users' viewing behavior they aim to prevent unhealthy usage. To inform users about taking a break from looking at a screen they provide feedback in form of vibration and LED light. First, when 20 minutes of screen viewing was detected (vibration pattern altering between long and short), second, when the user is looking at something 20 feet away (green/red LED light to indicate if distance ishas been met), and third when the user has completed the 20-second break (weak vibration). An evaluation showed that users considered the feedback by the device useful and stated that "it would help their eye health".

Ho et al. presented an application for smartphones that reminds users to keep a certain distance to the device [Ho et al. 2015]. The front camera of the smartphone was used to detect a user's face and compare it with a pre-recorded picture at a healthy distance. Authors did not find differences in effectiveness of different types of notifications, but observed that users preferred non-interrupting approaches, i.e., passive warnings that only occupied a small part of the screen. Interestingly, they also found that users developed an understanding of the correct distance after a few reminders. Therefore, participants did not perceive the warning as overly annoying, since the frequency of reminders decreased accordingly.

Chaturvedi et al. used peripheral vision to reduce looking at the small screens of AR glasses [Chaturvedi et al. 2019]. They found that using their system 50% of the participants looked less often on the small screen, because they perceived the information peripherally.

5.3 Screen Properties and UI Elements

For these types of causes systems to lower screen brightness were proposed, most prominently E-paper devices [Wen and Weber 2018]. Vasylevska et al. tested three levels of brightness with regard to their influence on task performance, cybersickness, users' comfort, and user preferences in VR HMDs [Vasylevska et al. 2019]. They argue that especially the brightness differences between for- and background in an HMD might cause eye strain and that it is important to consider the user's context and to avoid rapid and hard changes in brightness. Further, they suggest that the brightness changes when switching between real world and HMD should be compensated for. Similarly, Kim et al. transferred the concept of dark mode on computer screens to optical see-through HMDs, in order to decrease visual fatigue [Kim et al. 2019]. They applied this concept by displaying dark colors as transparent and bright colors as visible. In a user study they found that dark mode (bright letters on dark background) reduced eye strain, which was significantly lower than in bright mode (dark letters on bright background).

5.4 Vergence-Accommodation Conflict

We classified solution approaches into two areas, those that mechanically change the device in order to provide more than one focal plane, which would implicitly solve the problem (e.g., varifocal or multifocal displays), and a second area that refers to software-based solutions, inducing missing depth information in order to adapt viewing experience to the real world.

5.4.1 *Hardware Solutions.*

Liu et al. built a monocular optical see-through HMD based on a liquid lens that enables several addressable focal distances between the near point of convergence of the eyes up to infinity [Sheng Liu et al. 2008]. A first evaluation suggests that the device enables users to correctly accommodate to a certain depth as rendered by the display. In addition to adaptive lenses, monovision, which would comprise a simple technical solution, was investigated as a solution approach. Findings are somewhat diverse on this. Whereas Konrad et al.'s results indicate that participants slightly preferred the monovision condition over standard usage modes [Konrad et al. 2016], Koulieris et al. found in a similar experiment that the monovision condition increased visual discomfort [Koulieris et al. 2017]. A reason for this discrepancy can be different exposure times. While these were relatively short (a few seconds) in Konrad et al.'s experiment, participants were exposed 30 minutes in Koulieris et al.'s study, which makes results more meaningful in terms of long-term effects. Additionally, Konrad et al. asked for "general viewing experience" that is not specifically tailored towards eye strain, while Koulieris et al.'s subjective ratings explicitly addressed "eye irritation". Dunn analyzed the required gaze tracking accuracy that is needed to identify the correct focus point of a user in order to adapt the display to the according focal distance [Dunn 2019]. They conclude that for an average adult an eye tracking accuracy of at least $0.541°$ is needed, which is, however, hardly achievable using commercial eye trackers.

5.4.2 *Software Solutions.*

Gaze contingent or foveated rendering was proposed to reduce negative visual effects that stem from conflicting depth cues [Romero-Rondón et al. 2018], i.e., displaying depth information to better match human visual perception. As stated by Komogortsev and Khan, peripheral content should match human visual acuity in order to avoid eye strain, i.e., by reducing image resolution in the peripheral part and enhancing image quality in the foveal part [Komogortsev and Khan 2006]. One difficulty is to provide gaze prediction at real time in order to change image quality without users noticing them. Arabadzhiyska et al. suggested a way to update images not based on the current gaze position, but on predicting the next fixation location based on saccadic movement [Arabadzhiyska et al. 2017]. Hereby they leverage that during saccades quality mismatches are not perceivable due to saccadic suppression. Another approach was presented by Koulieris et al., who designed a gaze predictor based on recognizing object categories in games [Koulieris et al. 2016]. They leverage that player action, and thus a user's gaze point, closely correlates to the current state of the game, which allows them to make assumptions about where a user's gaze will point to. Woo et al. proposed to reduce discomfort by dividing content presentation into three parallax zones [Woo et al. 2012]. At this, they recommend to use positive parallax (behind the screen) for long-term events and negative parallax (in front of the screen) for emphasizing important short-time events. Negative parallax should not be used for long periods of time as it causes eye strain due to a strong decoupling of accommodation and vergence.

5.5 Dry Eye Syndrome

Dementyev and Holz presented a device that aims to alleviate dry eye syndrome by increasing blink rate [Dementyev and Holz 2017]. For this, they tested three types of actuation (light flashes, physical taps, and small puffs of air) that can be attached to a frame of glasses and found that air puffs near the user's eyes are most effective in increasing blink rate while having the lowest distraction value compared to the other techniques. Tang and Noor proposed a wearable humidifier device for the eyes [Tong Boon Tang and Noor 2015]. It measures humidity in a room and activates mist using a water pump if the humidity level is too low. Crnovrsanin et al. proposed four stimuli that were designed to trigger eye blinks during computer usage [Crnovrsanin et al. 2014]. They found that all stimuli achieved an increase in blink rate. Regarding the acceptance of strategies they found similar results to Ho et al.'s system [Ho et al. 2015]: the stimulus that covered the whole screen and appeared suddenly was liked less in contrast to stimuli that appeared in the peripheral field of view and occurred continuously. Authors also did not find a clear preference of stimuli in terms of effectiveness and preference and therefore proposed to let users decide on which stimuli they prefer to use.

5.6 Solutions to Active Causes

We found few authors that developed alternatives to explicit gaze interaction strategies that are known to contribute to DES. For instance, Piumsomboon et al. designed three techniques to integrate natural viewing behavior as gaze interaction techniques for VR HMDs [Piumsomboon et al. 2017]. Their techniques performed similarly to conventional gaze-dwell with better user experience ratings. However, they did not explicitly measure eye strain in their study, but argue that natural viewing behavior naturally produces less eye strain than artificial viewing behavior. Hansen et al. suggested that off-screen gestures could overcome the problem of eye strain with small displays (i.e., smart watch). However, they did not assess eye strain in the evaluation of their technique [Hansen et al. 2015]. Vasiljevas et al. investigated eye fatigue in an eye-based text entry system [Vasiljevas et al. 2016] stating that user interface design strongly influences eye fatigue, since a poorly designed system that for instance demands high amounts of visual search causes higher eye fatigue. Whereas a better designed system might delay occurrence of symptoms. Hsiao and Wei aimed to decrease visual discomfort that occurs due to screen vibration when using mobile devices while being in motion (e.g., in a bus or train) [Hsiao and Wei 2017]. The display stabilization technique that they proposed was tested with 20 participants and resulted in a more comfortable feeling during reading content on a tablet.

6 INSIGHTS

6.1 Challenges in Assesing DES

The first key challenge of assessing DES is the large *variety of measures*. To date several methods are used that vary in detail and accuracy, making it difficult to compare symptoms and causes across systems and interaction techniques. Although several subjective assessment scales were proposed, there is no common consensus on which one to use (see Table 3). Further, no consistent term for DES is used (e.g., visual fatigue or discomfort, eye fatigue), making it challenging to identify all relevant works to this topic. We presume that the inconsistency of terms and measures is one reason why a concise model that relates causes to symptoms does not exist yet. Second, dry eye has to be considered a special symptom given that it is the only one we found that is similarly symptom, as well as cause for other symptoms. Some works therefore focus on alleviating dry eye specifically [Mohan et al. 2018], however it is important to also consider and measure all other symptoms of DES.

6.2 Solutions and Causes

Since to date a concise model of causes and symptoms is missing, the occurrence of symptoms has not yet been conclusively determined, which makes it difficult to search for solutions. We summarized our findings on symptoms, causes, and solutions in Figure 3. In the following we list some limitations of current solution approaches, on the basis of which we make recommendations in the next section.

Solutions to the problem of *close viewing distance* often interrupt the user by sending recommendations [Jumpamule and Thapkun 2018], or are only applicable in a limited application area, since they require specific hardware modifications [Dementyev and Holz 2017]. This calls for new research into subtle methods to ensure a healthy viewing distance that work with off-the-shelf hardware. Solutions to *display and user interface element properties* are very device-specific. One approach that is applicable with more devices is to lower screen brightness [Vasylevska et al. 2019]. The impact of the *VA-conflict* on eye strain is seen somewhat controversial in literature. Whereas some argue for its impact being underrated [Szpak et al. 2019], others suggest that its impact might not be as strong as assumed [Zhang et al. 2019a]. In addition, Jacobs et al. suggest that the VA conflict is only one of straining factors for VR and other causes may be underestimated [Jacobs et al. 2019]. Our survey revealed a fundamental lack of solutions that address *active causes*. Of the 47 papers that focus on some type of gaze-based interaction only 4 explicit solutions were proposed. We found that gaze-based interaction techniques that minimize prolonged fixation duration and large number of long saccades perform better compared to other techniques. However, it seems this topic is only marginally considered, given the large amount of gaze-based interaction techniques. Therefore, it will be important that the gaze interaction community actively addresses the development of solutions for major explicit gaze interaction techniques. In summary, the literature points out that DES is not a generalizable problem, but that symptoms occur specifically for device type and interaction technique.

6.3 Mismatch of Awareness and Actions

The limited number of solutions seems to suggest a lack of awareness to DES as a problem in the gaze interaction community. Our survey suggests that this is rather a result of a mismatch between awareness and actions. A large number of gaze interaction-related papers reported medium to high values for DES. In most of these DES was assessed as an additional measure, but the results were often neither reported nor discussed. Additionally, and to some extent contradictory, we found that study designs are often adapted to reduce eye strain, e.g., by including breaks to let participants

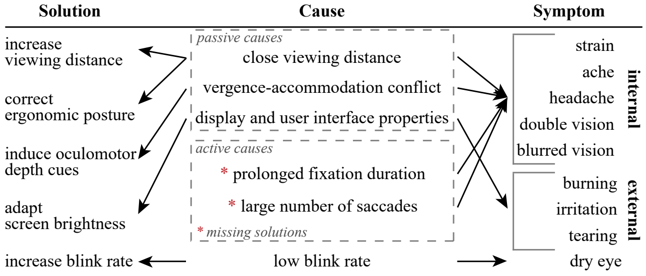

Figure 3: This Figure demonstrates the connection between solutions, causes, and symptoms as derived by the survey.

recover from possible eye strain [Ferrari and Yaoping Hu 2011; Ou et al. 2005, 2008; Pfeuffer et al. 2013; Wallace et al. 2004; Zhang et al. 2019b], limiting the number [Paulus et al. 2017] or duration [Larson et al. 2017] of trials, or by conducting an experiment over several days [Keyvanara and Allison 2019]. However, in these studies eye strain was often not measured or, if measured, not reported on or discussed. Often eye strain is mentioned in the limitations [Abdrabou et al. 2019] or future work [Pai et al. 2016; Räihä and Sharmin 2014; Rajanna and Hansen 2018] sections of a paper, or is addressed briefly as disruptive factor, experienced by some [Kudo et al. 2013; Lisle et al. 2018; Mattusch et al. 2018; Obrist et al. 2012] or even a majority [Ortega and Stuerzlinger 2018; Pastoor et al. 1999] of participants. However, implications are typically not further discussed. This suggest that while eye strain is a known problem in the community it has not yet been fully acknowledged and included in evaluating interaction devices and techniques. Since it is difficult to integrate eye-healthy behavior into existing gaze interaction techniques retrospectively, the assessment of DES should be included in early stages of development.

7 RECOMMENDATIONS

7.1 Assessment

The most important limitation in current research practice is that DES is not regularly assessed and not with consistent measurement methods. Similar to Grubert et al., who suggest to add eye strain assessment to the error metrics during calibration procedures on optical see-through HMDs [Grubert et al. 2018], we argue that eye strain should become an additional standard measure for the evaluation of new interaction devices and techniques. This is important for all systems that address users' eyes (i.e., displays in general), but especially for explicit gaze interaction. Second, researchers should assess symptoms specific to use cases. For instance, for stereoscopic displays it may be more important to focus the assessment on internal symptoms while for user interface properties external symptoms should be preferred. Third, none of the found papers conducted a longitudinal study. Considering the average interaction time of users with digital devices, it should be discussed how eye-based techniques scale to a longer time of use, pursuing real usage outside a study situation. Since long-term effects of DES in gaze interaction is currently severely overlooked, we recommend that explicit gaze interaction techniques should be assessed in long-term studies.

To integrate these points into common research practice, we suggest that a consistent methodology should be developed that focuses around internal and external symptoms and considers subjective, as well as objective measures. We argue that only once DES has become a default measure, results can be compared across systems. This way a more comprehensive picture of eye strain in gaze-based interactive systems can be established, also leading to a clearer understanding of symptoms and their causes.

7.2 Potential Solutions

We summarize the findings of our survey by providing a set of potential solutions that we believe future work should focus on.

Implicit Integration. We found that users are aware of DES and, even more importantly, care about their eye health. However they either do not know certain causes (e.g., close viewing distance [Ho et al. 2015]) or if they do, consider them not important enough to change their behavior. Therefore, we recommend to integrate solutions implicitly. In that, the alleviation and avoidance of DES should inherently be integrated in device usage and not be left to the user. It is rather the community's responsibility to build systems and interactions in a way that users are not being harmed.

Adaptation to User Preferences. Users have individual preferences of adaptation methods, e.g., whether visual recommendation stimuli occupy the whole or only parts of the screen [Crnovrsanin et al. 2014; Ho et al. 2015]. Future solutions should be explicitly designed to meet these preferences, such that users can choose the solution that fits their usage behaviour and physiology best [Ho et al. 2015].

There Is No One-Fits-All Solution. As shown in Figure 3 there exists no unique link between individual symptoms, causes, and solutions. Therefore, we recommend that only a set of different solutions can solve the problem. Solutions should thereby be explicitly designed to be expandable and connectable with other types of solutions.

To conclude, the gaze interaction community is in demand from two perspectives. First, it is important to share valuable insights on causes during the development of novel interaction devices and techniques. Secondly, the gaze interaction community is now in demand to search and develop solutions.

8 CONCLUSION

In this work we provided the first comprehensive survey of how DES is currently assessed and dealt with in gaze interaction research. Based on a systematic literature review that bridged the community of gaze interaction with digital eye strain, we found that: (1) gaze interaction techniques cause eye strain but these negative impacts are not further addressed, (2) there is no clear methodology how DES should be assessed and evaluated, and (3) current solutions almost only address symptoms that stem from looking at displays, but not from gaze interaction. Our work emphasizes that DES - if further neglected - will become a significant problem for gaze-based systems. To avoid this, a change in evaluation practices should take place and researchers in the gaze interaction community should develop alleviation techniques.

ACKNOWLEDGMENTS

The presented research was conducted within the project "Gaze-Assisted Scalable Interaction in Pervasive Classrooms" funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation, RU 1605/5-1).

REFERENCES

Yasmeen Abdrabou, Mohamed Khamis, Rana Mohamed Eisa, Sherif Ismail, and Amrl Elmougy. 2019. Just Gaze and Wave: Exploring the Use of Gaze and Gestures for Shoulder-surfing Resilient Authentication. In *Proceedings of the 11th ACM Symposium on Eye Tracking Research & Applications (ETRA '19)*. ACM, New York, NY, USA, Article 29, 10 pages. https://doi.org/10.1145/3314111.3319837

Elena Arabadzhiyska, Okan Tarhan Tursun, Karol Myszkowski, Hans-Peter Seidel, and Piotr Didyk. 2017. Saccade Landing Position Prediction for Gaze-contingent Rendering. *ACM Trans. Graph.* 36, 4, Article 50 (July 2017), 12 pages. https://doi.org/10.1145/3072959.3073642

Behrooz Ashtiani and I. Scott MacKenzie. 2010. BlinkWrite2: An Improved Text Entry Method Using Eye Blinks. In *Proceedings of the 2010 Symposium on Eye-Tracking Research; Applications (ETRA '10)*. ACM, New York, NY, USA, 339–345. https://doi.org/10.1145/1743666.1743742

Kayo Azuma and Hideki Koike. 2018. A Study on Gaze Guidance Using Artificial Color Shifts. In *Proceedings of the 2018 International Conference on Advanced Visual Interfaces (AVI '18)*. ACM, New York, NY, USA, Article 47, 5 pages. https://doi.org/10.1145/3206505.3206517

Terry Bahill and Lawrence Stark. 1975. Overlapping saccades and glissades are produced by fatigue in the saccadic eye movement system. *Experimental Neurology* 48, 1 (1975), 95 – 106. https://doi.org/10.1016/0014-4886(75)90225-3

Robert Kerwin Billones, Rhen Anjerome Bedruz, Madon Arcega, Gabriela Eustaqio, Diana Guehring, Ramon Tupaz, Ira Valenzuela, and Elmer Dadios. 2018. Digital Eye Strain and Fatigue Recognition Using Electrooculogram Signals and Ultrasonic Distance Measurements. In *2018 IEEE 10th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment and Management (HNICEM)*. IEEE, 1–6. https://doi.org/10.1109/HNICEM.2018.8666298

Pradipta Biswas and Pat Langdon. 2013. A New Interaction Technique Involving Eye Gaze Tracker and Scanning System. In *Proceedings of the 2013 Conference on Eye Tracking South Africa (ETSA '13)*. ACM, New York, NY, USA, 67–70. https://doi.org/10.1145/2509315.2509322

Clayton Blehm, Seema Vishnu, Ashbala Khattak, Shrabanee Mitra, and Richard W. Yee. 2005. Computer Vision Syndrome: A Review. *Survey of Ophthalmology* 50, 3 (2005), 253 – 262. https://doi.org/10.1016/j.survophthal.2005.02.008

Pieter Blignaut. 2013. A New Mapping Function to Improve the Accuracy of a Video-based Eye Tracker. In *Proceedings of the South African Institute for Computer Scientists and Information Technologists Conference (SAICSIT '13)*. ACM, New York, NY, USA, 56–59. https://doi.org/10.1145/2513456.2513461

Andreas Bulling and Kai Kunze. 2016. EyeWear Computers for Human-Computer Interaction. *ACM Interactions* 23, 3 (2016), 70–73. https://doi.org/10.1145/2912886

Marcus Carter, Joshua Newn, Eduardo Velloso, and Frank Vetere. 2015. Remote Gaze and Gesture Tracking on the Microsoft Kinect: Investigating the Role of Feedback. In *Proceedings of the Annual Meeting of the Australian Special Interest Group for Computer Human Interaction (OzCHI '15)*. ACM, New York, NY, USA, 167–176. https://doi.org/10.1145/2838739.2838778

Tuhin Chakraborty, Sayan Sarcar, and Debasis Samanta. 2014. Design and Evaluation of a Dwell-free Eye Typing Technique. In *Proceedings of the Extended Abstracts of the 32nd Annual ACM Conference on Human Factors in Computing Systems (CHI EA '14)*. ACM, New York, NY, USA, 1573–1578. https://doi.org/10.1145/2559206.2581265

Isha Chaturvedi, Farshid Hassani Bijarbooneh, Tristan Braud, and Pan Hui. 2019. Peripheral Vision: A New Killer App for Smart Glasses. In *Proceedings of the 24th International Conference on Intelligent User Interfaces (IUI '19)*. ACM, New York, NY, USA, 625–636. https://doi.org/10.1145/3301275.3302263

Chun-Ching Chen and Yen-Yi Huang. 2018. Exploring the effect of color on the gaze input interface. In *2018 IEEE International Conference on Applied System Invention (ICASI)*. IEEE, 620–623. https://doi.org/10.1109/ICASI.2018.8394331

Chun-Ching Chen, Tommi Määttä, Kevin Bing-Yung Wong, and Hamid Aghajan. 2012. A collaborative framework for ergonomic feedback using smart cameras. In *2012 Sixth International Conference on Distributed Smart Cameras (ICDSC)*. IEEE, 1–6.

Juanita D. Collier and Mark Rosenfield. 2011. Accommodation and convergence during sustained computer work. *Optometry - Journal of the American Optometric Association* 82, 7 (2011), 434 – 440. https://doi.org/10.1016/j.optm.2010.10.013

Tarik Crnovrsanin, Yang Wang, and Kwan-Liu Ma. 2014. Stimulating a Blink: Reduction of Eye Fatigue with Visual Stimulus. In *Proceedings of the 32Nd Annual ACM Conference on Human Factors in Computing Systems (CHI '14)*. ACM, New York, NY, USA, 2055–2064. https://doi.org/10.1145/2556288.2557129

Hugh Davson. 1990. *Physiology of the Eye.* Macmillan International Higher Education.

María del Mar Seguí, Julio Cabrero-García, Ana Crespo, José Verdú, and Elena Ronda. 2015. A reliable and valid questionnaire was developed to measure computer vision syndrome at the workplace. *Journal of Clinical Epidemiology* 68, 6 (2015), 662 – 673. https://doi.org/10.1016/j.jclinepi.2015.01.015

Artem Dementyev and Christian Holz. 2017. DualBlink: A Wearable Device to Continuously Detect, Track, and Actuate Blinking For Alleviating Dry Eyes and Computer Vision Syndrome. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 1, 1, Article 1 (March 2017), 19 pages. https://doi.org/10.1145/3053330

Thomas W. Dillon and Henry H. Emurian. 1996. Some factors affecting reports of visual fatigue resulting from use of a VDU. *Computers in Human Behavior* 12, 1 (1996), 49 – 59. https://doi.org/10.1016/0747-5632(95)00018-6

Andrew T Duchowski. 2007. *Eye tracking methodology.* Springer.

David Dunn. 2019. Required Accuracy of Gaze Tracking for Varifocal Displays. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE, 1838–1842. https://doi.org/10.1109/VR.2019.8798273

Alex Endert, Lauren Bradel, Jessica Zeitz, Christopher Andrews, and Chris North. 2012. Designing Large High-resolution Display Workspaces. In *Proceedings of the International Working Conference on Advanced Visual Interfaces (AVI '12)*. ACM, New York, NY, USA, 58–65. https://doi.org/10.1145/2254556.2254570

Simon Ferrari and Yaoping Hu. 2011. The effect of incongruent delay on guided haptic training. In *2011 IEEE World Haptics Conference*. IEEE, 161–166. https://doi.org/10.1109/WHC.2011.5945479

Yulia Gizatdinova, Oleg Špakov, Outi Tuisku, Matthew Turk, and Veikko Surakka. 2018. Gaze and Head Pointing for Hands-free Text Entry: Applicability to Ultra-small Virtual Keyboards. In *Proceedings of the 2018 ACM Symposium on Eye Tracking Research & Applications (ETRA '18)*. ACM, New York, NY, USA, Article 14, 9 pages. https://doi.org/10.1145/3204493.3204539

Jens Grubert, Yuta Itoh, Kenneth Moser, and J. Edward Swan. 2018. A Survey of Calibration Methods for Optical See-Through Head-Mounted Displays. *IEEE Transactions on Visualization and Computer Graphics* 24, 9 (Sep. 2018), 2649–2662. https://doi.org/10.1109/TVCG.2017.2754257

Jukka Häkkinen, Monika Pölönen, Jari Takatalo, and Göte Nyman. 2006. Simulator Sickness in Virtual Display Gaming: A Comparison of Stereoscopic and Non-stereoscopic Situations. In *Proceedings of the 8th Conference on Human-computer Interaction with Mobile Devices and Services (MobileHCI '06)*. ACM, New York, NY, USA, 227–230. https://doi.org/10.1145/1152215.1152263

John Paulin Hansen, Florian Biermann, Janus Askø Madsen, Morten Jonassen, Haakon Lund, Javier San Agustin, and Sebastian Sztuk. 2015. A Gaze Interactive Textual Smartwatch Interface. 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)*. ACM, New York, NY, USA, 839–847. https://doi.org/10.1145/2800835.2804332

Jutta Hild, Dennis Gill, and Jürgen Beyerer. 2014. Comparing Mouse and MAGIC Pointing for Moving Target Acquisition. In *Proceedings of the Symposium on Eye Tracking Research and Applications (ETRA '14)*. ACM, New York, NY, USA, 131–134. https://doi.org/10.1145/2578153.2578172

Jutta Hild, Christian Kühnle, and Jürgen Beyerer. 2016. Gaze-based Moving Target Acquisition in Real-time Full Motion Video. In *Proceedings of the Ninth Biennial ACM Symposium on Eye Tracking Research and Applications (ETRA '16)*. ACM, New York, NY, USA, 241–244. https://doi.org/10.1145/2857491.2857525

Jimmy Ho, Reinhard Pointner, Huai-Chun Shih, Yu-Chih Lin, Hsuan-Yu Chen, Wei-Luan Tseng, and Mike Y. Chen. 2015. EyeProtector: Encouraging a Healthy Viewing Distance when Using Smartphones. In *Proceedings of the 17th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI '15)*. ACM, New York, NY, USA, 77–85. https://doi.org/10.1145/2785830.2785836

David M. Hoffman, Ahna Reza Girshick, Kurt Akeley, and Martin S. Banks. 2008. Vergence–accommodation conflicts hinder visual performance and cause visual fatigue. *Journal of Vision* 8, 3 (03 2008), 33–33. https://doi.org/10.1167/8.3.33

Peter Alan Howarth and Howell Owen Istance. 1985. The association between visual discomfort and the use of visual display units. *Behaviour & Information Technology* 4, 2 (1985), 131–149. https://doi.org/10.1080/01449298508901794

H. Hsiao and J. Wei. 2017. A real-time visual tracking technique for mobile display stabilization. In *2017 International Conference on Applied System Innovation (ICASI)*. IEEE, 440–442. https://doi.org/10.1109/ICASI.2017.7988447

Shoya Ishimaru, Kai Kunze, Katsuma Tanaka, Yuji Uema, Koichi Kise, and Masahiko Inami. 2015. Smart Eyewear for Interaction and Activity Recognition. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '15)*. ACM, New York, NY, USA, 307–310. https://doi.org/10.1145/2702613.2725449

Mohsina Ishrat and Pawanesh Abrol. 2017. Eye movement analysis in the context of external stimuli effect. In *2017 International Conference on Informatics, Health Technology (ICIHT)*. IEEE, 1–6. https://doi.org/10.1109/ICIHT.2017.7899148

Jochen Jacobs, Xi Wang, and Marc Alexa. 2019. Keep It Simple: Depth-based Dynamic Adjustment of Rendering for Head-mounted Displays Decreases Visual Comfort. *ACM Trans. Appl. Percept.* 16, 3, Article 16 (Sept. 2019), 16 pages. https://doi.org/10.1145/3353902

Watcharee Jumpamule and Tanakron Thapkun. 2018. Reminding System for Safety Smartphone Using to Reduce Symptoms of Computer Vision Syndrome. In *2018 22nd International Computer Science and Engineering Conference (ICSEC)*. IEEE, 1–4. https://doi.org/10.1109/ICSEC.2018.8712747

Robert Kennedy, Norman Lane, Kevin Berbaum, and Michael Lilienthal. 1993. Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness. *The International Journal of Aviation Psychology* 3, 3 (1993), 203–220. https://doi.org/10.1207/s15327108ijap0303_3

Maryam Keyvanara and Robert Allison. 2019. Transsaccadic Awareness of Scene Transformations in a 3D Virtual Environment. In *ACM Symposium on Applied Perception 2019 (SAP '19)*. ACM, New York, NY, USA, Article 19, 9 pages. https://doi.org/10.1145/3343036.3343121

Joohwan Kim, David Kane, and Martin S. Banks. 2014. The rate of change of vergence–accommodation conflict affects visual discomfort. *Vision Research* 105 (2014), 159 – 165. https://doi.org/10.1016/j.visres.2014.10.021

Kangsoo Kim, Austin Erickson, Alexis Lambert, Gerd Bruder, and Greg Welch. 2019. Effects of Dark Mode on Visual Fatigue and Acuity in Optical See-Through Head-Mounted Displays. In *Symposium on Spatial User Interaction (SUI '19)*. ACM, New York, NY, USA, Article 9, 9 pages. https://doi.org/10.1145/3357251.3357584

Do Hyong Koh, Sandeep A. Munikrishne Gowda, and Oleg V. Komogortsev. 2009. Input Evaluation of an Eye-gaze-guided Interface: Kalman Filter vs. Velocity Threshold Eye Movement Identification. In *Proceedings of the 1st ACM SIGCHI Symposium on Engineering Interactive Computing Systems (EICS '09)*. ACM, New York, NY, USA, 197–202. https://doi.org/10.1145/1570433.1570470

Oleg Komogortsev and Javed Khan. 2006. Perceptual Attention Focus Prediction for Multiple Viewers in Case of Multimedia Perceptual Compression with Feedback Delay. In *Proceedings of the 2006 Symposium on Eye Tracking Research & Applications (ETRA '06)*. ACM, New York, NY, USA, 101–108. https://doi.org/10.1145/1117309.1117352

Robert Konrad, Emily A. Cooper, and Gordon Wetzstein. 2016. Novel Optical Configurations for Virtual Reality: Evaluating User Preference and Performance with Focus-tunable and Monovision Near-eye Displays. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 1211–1220. https://doi.org/10.1145/2858036.2858140

George-Alex Koulieris, Bee Bui, Martin S. Banks, and George Drettakis. 2017. Accommodation and Comfort in Head-Mounted Displays. *ACM Trans. Graph.* 36, 4, Article Article 87 (July 2017), 11 pages. https://doi.org/10.1145/3072959.3073622

George Alex Koulieris, George Drettakis, Douglas Cunningham, and Katerina Mania. 2016. Gaze prediction using machine learning for dynamic stereo manipulation in games. In *2016 IEEE Virtual Reality (VR)*. 113–120. https://doi.org/10.1109/VR.2016.7504694

Rotem Kronenberg and Tsvi Kuflik. 2019. Automatically Adjusting Computer Screen. In *Adjunct Publication of the 27th Conference on User Modeling, Adaptation and Personalization (UMAP'19 Adjunct)*. ACM, New York, NY, USA, 51–56. https://doi.org/10.1145/3314183.3324980

Shinya Kudo, Hiroyuki Okabe, Taku Hachisu, Michi Sato, Shogo Fukushima, and Hiroyuki Kajimoto. 2013. Input Method Using Divergence Eye Movement. In *CHI '13 Extended Abstracts on Human Factors in Computing Systems (CHI EA '13)*. ACM, New York, NY, USA, 1335–1340. https://doi.org/10.1145/2468356.2468594

Kuno Kurzhals, Emine Cetinkaya, Yongtao Hu, Wenping Wang, and Daniel Weiskopf. 2017. Close to the Action: Eye-Tracking Evaluation of Speaker-Following Subtitles. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. ACM, New York, NY, USA, 6559–6568. https://doi.org/10.1145/3025453.3025772

Alex Larson, Joshua Herrera, Kiran George, and Aaron Matthews. 2017. Electrooculography based electronic communication device for individuals with ALS. In *2017 IEEE Sensors Applications Symposium (SAS)*. IEEE, 1–5. https://doi.org/10.1109/SAS.2017.7894062

Zhenxing Li, Deepak Akkil, and Roope Raisamo. 2019. Gaze Augmented Hand-Based Kinesthetic Interaction: What You See is What You Feel. *IEEE Transactions on Haptics* 12, 2 (April 2019), 114–127. https://doi.org/10.1109/TOH.2019.2896027

Lee Lisle, Kyle Tanous, Hyungil Kim, Joseph L. Gabbard, and Doug A. Bowman. 2018. Effect of Volumetric Displays on Depth Perception in Augmented Reality. In *Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI '18)*. ACM, New York, NY, USA, 155–163. https://doi.org/10.1145/3239060.3239083

Päivi Majaranta, Ulla-Kaija Ahola, and Oleg Špakov. 2009. Fast Gaze Typing with an Adjustable Dwell Time. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '09)*. ACM, New York, NY, USA, 357–360. https://doi.org/10.1145/1518701.1518758

Päivi Majaranta and Andreas Bulling. 2014. *Eye Tracking and Eye-Based Human–Computer Interaction*. Springer London, London, 39–65. https://doi.org/10.1007/978-1-4471-6392-3_3

Thomas Mattusch, Mahsa Mirzamohammad, Mohamed Khamis, Andreas Bulling, and Florian Alt. 2018. Hidden Pursuits: Evaluating Gaze-selection via Pursuits when the Stimuli's Trajectory is Partially Hidden. In *Proceedings of the 2018 ACM Symposium on Eye Tracking Research & Applications (ETRA '18)*. ACM, New York, NY, USA, Article 27, 5 pages. https://doi.org/10.1145/3204493.3204569

Biljana Miljanović, Reza Dana, David A. Sullivan, and Debra A. Schaumberg. 2007. Impact of Dry Eye Syndrome on Vision-Related Quality of Life. *American Journal of Ophthalmology* 143, 3 (2007), 409 – 415.e2. https://doi.org/10.1016/j.ajo.2006.11.060

Chulhong Min, Euihyeok Lee, Souneil Park, and Seungwoo Kang. 2019. Tiger: Wearable Glasses for the 20-20-20 Rule to Alleviate Computer Vision Syndrome. In *Proceedings of the 21st International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI '19)*. ACM, New York, NY, USA, Article 6, 11 pages. https://doi.org/10.1145/3338286.3340117

P. Mohan, W. B. Goh, C. Fu, and S. Yeung. 2018. DualGaze: Addressing the Midas Touch Problem in Gaze Mediated VR Interaction. In *2018 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*. IEEE, 79–84. https://doi.org/10.1109/ISMAR-Adjunct.2018.00039

David Moher, Alessandro Liberati, Jennifer Tetzlaff, Douglas G. Altman, , and the PRISMA Group. 2009. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *Annals of Internal Medicine* 151, 4 (08 2009), 264–269. https://doi.org/10.7326/0003-4819-151-4-200908180-00135 arXiv:https://annals.org/acp/content_public/journal/aim/20188/0000605-200908180-00008.pdf

Carlos H. Morimoto and Arnon Amir. 2010. Context Switching for Fast Key Selection in Text Entry Applications. In *Proceedings of the 2010 Symposium on Eye-Tracking Research; Applications (ETRA '10)*. ACM, New York, NY, USA, 271–274. https://doi.org/10.1145/1743666.1743730

Carlos H. Morimoto, Jose A. T. Leyva, and Antonio Diaz-Tula. 2018. Context Switching Eye Typing Using Dynamic Expanding Targets. In *Proceedings of the Workshop on Communication by Gaze Interaction (COGAIN '18)*. ACM, New York, NY, USA, Article 6, 9 pages. https://doi.org/10.1145/3206343.3206347

Ivana Nakarada-Kordic and Brenda Lobb. 2005. Effect of Perceived Attractiveness of Web Interface Design on Visual Search of Web Sites. In *Proceedings of the 6th ACM SIGCHI New Zealand Chapter's International Conference on Computer-human Interaction: Making CHI Natural (CHINZ '05)*. ACM, New York, NY, USA, 25–27. https://doi.org/10.1145/1073943.1073949

Bibhukalyan Prasad Nayak, Sibsambhu Kar, Aurobinda Routray, and Akhaya Kumar Padhi. 2012. A biomedical approach to retrieve information on driver's fatigue by integrating EEG, ECG and blood biomarkers during simulated driving session. In *2012 4th International Conference on Intelligent Human Computer Interaction (IHCI)*. IEEE, 1–6. https://doi.org/10.1109/IHCI.2012.6481812

Aanand Nayyar, Utkarsh Dwivedi, Karan Ahuja, Nitendra Rajput, Seema Nagar, and Kuntal Dey. 2017. OptiDwell: Intelligent Adjustment of Dwell Click Time. In *Proceedings of the 22Nd International Conference on Intelligent User Interfaces (IUI '17)*. ACM, New York, NY, USA, 193–204. https://doi.org/10.1145/3025171.3025202

Joshua Newn, Eduardo Velloso, Marcus Carter, and Frank Vetere. 2016. Multimodal Segmentation on a Large Interactive Tabletop: Extending Interaction on Horizontal Surfaces with Gaze. In *Proceedings of the 2016 ACM International Conference on Interactive Surfaces and Spaces (ISS '16)*. ACM, New York, NY, USA, 251–260. https://doi.org/10.1145/2992154.2992179

Marianna Obrist, Daniela Wurhofer, Florian Förster, Thomas Meneweger, Thomas Grill, David Wilfinger, and Manfred Tscheligi. 2011. Perceived 3DTV Viewing in the Public: Insights from a Three-day Field Evaluation Study. In *Proceedings of the 9th European Conference on Interactive TV and Video (EuroITV '11)*. ACM, New York, NY, USA, 167–176. https://doi.org/10.1145/2000119.2000154

Marianna Obrist, Daniela Wurhofer, Magdalena Gärtner, Florian Förster, and Manfred Tscheligi. 2012. Exploring Children's 3DTV Experience. In *Proceedings of the 10th European Conference on Interactive TV and Video (EuroITV '12)*. ACM, New York, NY, USA, 125–134. https://doi.org/10.1145/2325616.2325641

Masako Omori, Asei Sugiyama, Hiroki Hori, Tomoki Shiomi, Tetsuya Kanda, Akira Hasegawa, Hiromu Ishio, Hiroki Takada, Satoshi Hasegawa, and Masaru Miyao. 2011. Effect of Weak Hyperopia on Stereoscopic Vision. In *Virtual and Mixed Reality - New Trends*, Randall Shumaker (Ed.). Springer Berlin Heidelberg, Berlin, Heidelberg, 354–362.

Choon Nam Ong, David Koh, and W.O.Phoon. 1988. Review and reappraisal of health hazards of display terminals. *Displays* 9, 1 (1988), 3 – 13. https://doi.org/10.1016/0141-9382(88)90106-0

Michaël Ortega and Wolfgang Stuerzlinger. 2018. Pointing at Wiggle 3D Displays. In *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE, 335–340. https://doi.org/10.1109/VR.2018.8447552

Jiazhi Ou, Lui Min Oh, Susan R. Fussell, Tal Blum, and Jie Yang. 2005. Analyzing and Predicting Focus of Attention in Remote Collaborative Tasks. In *Proceedings of the 7th International Conference on Multimodal Interfaces (ICMI '05)*. ACM, New York, NY, USA, 116–123. https://doi.org/10.1145/1088463.1088485

Jiazhi Ou, Lui Min Oh, S. R. Fussell, T. Blum, and Jie Yang. 2008. Predicting Visual Focus of Attention From Intention in Remote Collaborative Tasks. *IEEE Transactions on Multimedia* 10, 6 (Oct 2008), 1034–1045. https://doi.org/10.1109/TMM.2008.2001363

Yun Suen Pai, Benjamin Outram, Noriyasu Vontin, and Kai Kunze. 2016. Transparent Reality: Using Eye Gaze Focus Depth As Interaction Modality. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology (UIST '16 Adjunct)*. ACM, New York, NY, USA, 171–172. https://doi.org/10.1145/2984751.2984754

Min-Chul Park and Sungchul Mun. 2015. Overview of Measurement Methods for Factors Affecting the Human Visual System in 3D Displays. *Journal of Display Technology* 11, 11 (Nov 2015), 877–888. https://doi.org/10.1109/JDT.2015.2389212

S. Pastoor, Jin Liu, and Sylvain Renault. 1999. An experimental multimedia system allowing 3-D visualization and eye-controlled interaction without user-worn devices. *IEEE Transactions on Multimedia* 1, 1 (March 1999), 41–52. https://doi.org/10.1109/6046.748170

Sudi Patel, Ross Munro Henderson, L. Bradley, B. Galloway, and L. Hunter. 1991. Effect of Visual Display Unit Use on Blink Rate and Tear Stability. *Optometry and Vision*

Science 68, 11 (1991), 888–892. https://doi.org/10.1097/00006324-199111000-00010

Yesaya Tommy Paulus, Chihiro Hiramatsu, Yvonne Kam Hwei Syn, and Gerard B. Remijn. 2017. Measurement of viewing distances and angles for eye tracking under different lighting conditions. In *2017 2nd International Conference on Automation, Cognitive Science, Optics, Micro Electro-Mechanical System, and Information Technology (ICACOMIT)*. IEEE, 54–58. https://doi.org/10.1109/ICACOMIT.2017.8253386

Kevin Pfeil, Eugene M. Taranta, II, Arun Kulshreshth, Pamela Wisniewski, and Joseph J. LaViola, Jr. 2018. A Comparison of Eye-head Coordination Between Virtual and Physical Realities. In *Proceedings of the 15th ACM Symposium on Applied Perception (SAP '18)*. ACM, New York, NY, USA, Article 18, 7 pages. https://doi.org/10.1145/3225153.3225157

Ken Pfeuffer, Jason Alexander, and Hans Gellersen. 2016. Partially-indirect Bimanual Input with Gaze, Pen, and Touch for Pan, Zoom, and Ink Interaction. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 2845–2856. https://doi.org/10.1145/2858036.2858201

Ken Pfeuffer, Melodie Vidal, Jayson Turner, Andreas Bulling, and Hans Gellersen. 2013. Pursuit Calibration: Making Gaze Calibration Less Tedious and More Flexible. In *Proceedings of the 26th Annual ACM Symposium on User Interface Software and Technology (UIST '13)*. ACM, New York, NY, USA, 261–270. https://doi.org/10.1145/2501988.2501998

Thammathip Piumsomboon, Gun Lee, Robert W. Lindeman, and Mark Billinghurst. 2017. Exploring natural eye-gaze-based interaction for immersive virtual reality. In *2017 IEEE Symposium on 3D User Interfaces (3DUI)*. IEEE, 36–39. https://doi.org/10.1109/3DUI.2017.7893315

Joan K Portello, Mark Rosenfield, and Christina A Chu. 2013. Blink rate, incomplete blinks and computer vision syndrome. *Optometry and Vision Science* 90, 5 (2013), 482–487. https://doi.org/10.1097/OPX.0b013e31828f09a7

Felix Putze, Johannes Popp, Jutta Hild, Jürgen Beyerer, and Tanja Schultz. 2016. Intervention-free Selection Using EEG and Eye Tracking. In *Proceedings of the 18th ACM International Conference on Multimodal Interaction (ICMI '16)*. ACM, New York, NY, USA, 153–160. https://doi.org/10.1145/2993148.2993199

Yuan Yuan Qian and Robert J. Teather. 2017. The Eyes Don'T Have It: An Empirical Comparison of Head-based and Eye-based Selection in Virtual Reality. In *Proceedings of the 5th Symposium on Spatial User Interaction (SUI '17)*. ACM, New York, NY, USA, 91–98. https://doi.org/10.1145/3131277.3132182

Kari-Jouko Räihä and Selina Sharmin. 2014. Gaze-contingent Scrolling and Reading Patterns. In *Proceedings of the 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational (NordiCHI '14)*. ACM, New York, NY, USA, 65–68. https://doi.org/10.1145/2639189.2639242

Vijay Rajanna. 2016. Gaze Typing Through Foot-Operated Wearable Device. In *Proceedings of the 18th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '16)*. ACM, New York, NY, USA, 345–346. https://doi.org/10.1145/2982142.2982145

Vijay Rajanna and Tracy Hammond. 2016. GAWSCHI: Gaze-augmented, Wearable-supplemented Computer-human Interaction. In *Proceedings of the Ninth Biennial ACM Symposium on Eye Tracking Research & Applications (ETRA '16)*. ACM, New York, NY, USA, 233–236. https://doi.org/10.1145/2857491.2857499

Vijay Rajanna and Tracy Hammond. 2018. A Fitts' Law Evaluation of Gaze Input on Large Displays Compared to Touch and Mouse Inputs. In *Proceedings of the Workshop on Communication by Gaze Interaction (COGAIN '18)*. ACM, New York, NY, USA, Article 8, 5 pages. https://doi.org/10.1145/3206343.3206348

Vijay Rajanna and John Paulin Hansen. 2018. Gaze Typing in Virtual Reality: Impact of Keyboard Design, Selection Method, and Motion. In *Proceedings of the 2018 ACM Symposium on Eye Tracking Research & Applications (ETRA '18)*. ACM, New York, NY, USA, Article 15, 10 pages. https://doi.org/10.1145/3204493.3204541

Photchara Ratsamee, Yasushi Mae, Kazuto Kamiyama, Mitsuhiro Horade, Masaru Kojima, Kiyoshi Kiyokawa, Tomohiro Mashita, Yoshihiro Kuroda, Haruo Takemura, and Tatsuo Arai. 2015. Object search framework based on gaze interaction. In *2015 IEEE International Conference on Robotics and Biomimetics (ROBIO)*. IEEE, 1997–2002. https://doi.org/10.1109/ROBIO.2015.7419066

Stephan Reichelt, Ralf Häussler, Gerald Fütterer, and Norbert Leister. 2010. Depth cues in human visual perception and their realization in 3D displays. In *Three-Dimensional Imaging, Visualization, and Display 2010 and Display Technologies and Applications for Defense, Security, and Avionics IV*, Bahram Javidi, Jung-Young Son, John Tudor Thomas, and Daniel D. Desjardins (Eds.), Vol. 7690. International Society for Optics and Photonics, SPIE, 92 – 103. https://doi.org/10.1117/12.850094

Allan G. Rempel, Wolfgang Heidrich, Hiroe Li, and RafałMantiuk. 2009. Video Viewing Preferences for HDR Displays Under Varying Ambient Illumination. In *Proceedings of the 6th Symposium on Applied Perception in Graphics and Visualization (APGV '09)*. ACM, New York, NY, USA, 45–52. https://doi.org/10.1145/1620993.1621004

Miguel Fabian Romero-Rondón, Lucile Sassatelli, Frédéric Precioso, and Ramon Aparicio-Pardo. 2018. Foveated Streaming of Virtual Reality Videos. In *Proceedings of the 9th ACM Multimedia Systems Conference (MMSys '18)*. ACM, New York, NY, USA, 494–497. https://doi.org/10.1145/3204949.3208114

Mark Rosenfield. 2011. Computer vision syndrome: a review of ocular causes and potential treatments. *Ophthalmic & physiological optics : the journal of the British College of Ophthalmic Opticians (Optometrists)* 31, 5 (September 2011), 502–515. https://doi.org/10.1111/j.1475-1313.2011.00834.x

Mark Rosenfield. 2016. Computer vision syndrome (aka digital eye strain). *Optometry* 17, 1 (2016), 1–10.

Torsten Schlote, Gregor Kadner, and Nora Freudenthaler. 2004. Marked reduction and distinct patterns of eye blinking in patients with moderately dry eyes during video display terminal use. *Graefe's Archive for Clinical and Experimental Ophthalmology* 242, 4 (01 Apr 2004), 306–312. https://doi.org/10.1007/s00417-003-0845-z

Pieter Seuntiens, Lydia Meesters, and Wijnand Ijsselsteijn. 2006. Perceived Quality of Compressed Stereoscopic Images: Effects of Symmetric and Asymmetric JPEG Coding and Camera Separation. *ACM Trans. Appl. Percept.* 3, 2 (April 2006), 95–109. https://doi.org/10.1145/1141897.1141899

James E Sheedy, John N Hayes, and Jon Engle. 2003. Is all asthenopia the same? *Optometry and vision science : official publication of the American Academy of Optometry* 80, 11 (November 2003), 732—739. https://doi.org/10.1097/00006324-200311000-00008

Sheng Liu, Dewen Cheng, and Hong Hua. 2008. An optical see-through head mounted display with addressable focal planes. In *2008 7th IEEE/ACM International Symposium on Mixed and Augmented Reality*. IEEE, 33–42. https://doi.org/10.1109/ISMAR.2008.4637321

Takashi Shibata, Joohwan Kim, David M. Hoffman, and Martin S. Banks. 2011. Visual discomfort with stereo displays: effects of viewing distance and direction of vergence-accommodation conflict. In *Stereoscopic Displays and Applications XXII*, Andrew J. Woods, Nicolas S. Holliman, and Neil A. Dodgson (Eds.), Vol. 7863. International Society for Optics and Photonics, SPIE, 222 – 230. https://doi.org/10.1117/12.872347

Xiaojuan Ma Jodi L. Forlizzi Scott E. Hudson Anind Dey Shiwei Cheng, Zhiqiang Sun. 2015. Social Eye Tracking: Gaze Recall with Online Crowds. In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work; Social Computing (CSCW '15)*. ACM, New York, NY, USA, 454–463. https://doi.org/10.1145/2675133.2675249

Alexis D. Souchet, Stéphanie Philippe, Dimitri Zobel, Floriane Ober, Aurélien Lévêque, and Laure Leroy. 2018. Eyestrain Impacts on Learning Job Interview with a Serious Game in Virtual Reality: A Randomized Double-blinded Study. In *Proceedings of the 24th ACM Symposium on Virtual Reality Software and Technology (VRST '18)*. ACM, New York, NY, USA, Article 15, 12 pages. https://doi.org/10.1145/3281505.3281509

G. H. Stickney. 1919. Present Status of Industrial Lighting Codes. *Transactions of the American Institute of Electrical Engineers* XXXVIII, 1 (Jan 1919), 725–765. https://doi.org/10.1109/T-AIEE.1919.4765617

Ancrêt Szpak, Stefan Carlo Michalski, Dimitrios Saredakis, Celia S. Chen, and Tobias Loetscher. 2019. Beyond Feeling Sick: The Visual and Cognitive Aftereffects of Virtual Reality. *IEEE Access* 7 (2019), 130883–130892. https://doi.org/10.1109/ACCESS.2019.2940073

Masumi Takada, Masaru Miyao, and Hiroki Takada. 2015. Subjective evaluation of peripheral viewing during exposure to a 2D/3D video clip. In *2015 IEEE Virtual Reality (VR)*. IEEE, 291–292. https://doi.org/10.1109/VR.2015.7223410

Tong Boon Tang and Nur Haedzerlin Md Noor. 2015. Towards wearable active humidifier for dry eyes. In *2015 IEEE International Circuits and Systems Symposium (ICSyS)*. IEEE, 116–119. https://doi.org/10.1109/CircuitsAndSystems.2015.7394076

Chinatsu Tosha, Eric Borsting, William H. Ridder III, and Chris Chase. 2009. Accommodation response and visual discomfort. *Ophthalmic and Physiological Optics* 29, 6 (2009), 625–633. https://doi.org/10.1111/j.1475-1313.2009.00687.x

Mindaugas Vasiljevas, T. Gedminas, A. Ševčenko, M. Jančiukas, T. Blažauskas, and R. Damaševičius. 2016. Modelling eye fatigue in gaze spelling task. In *2016 IEEE 12th International Conference on Intelligent Computer Communication and Processing (ICCP)*. IEEE, 95–102. https://doi.org/10.1109/ICCP.2016.7737129

Khrystyna Vasylevska, Hyunjin Yoo, Tara Akhavan, and Hannes Kaufmann. 2019. Towards Eye-Friendly VR: How Bright Should It Be?. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. 566–574. https://doi.org/10.1109/VR.2019.8797752

Cyril Vienne, Laurent Sorin, Laurent Blondé, Quan Huynh-Thu, and Pascal Mamassian. 2014. Effect of the accommodation-vergence conflict on vergence eye movements. *Vision Research* 100 (2014), 124 – 133. https://doi.org/10.1016/j.visres.2014.04.017

Andrew Wallace, Joshua Savage, and Andy Cockburn. 2004. Rapid Visual Flow: How Fast is Too Fast?. In *Proceedings of the Fifth Conference on Australasian User Interface - Volume 28 (AUIC '04)*. Australian Computer Society, Inc., Darlinghurst, Australia, Australia, 117–122. http://dl.acm.org/citation.cfm?id=976310.976325

Yan Wang, Guangtao Zhai, Shaoqian Zhou, Sichao Chen, Xiongkuo Min, Zhongpai Gao, and Meng-Han Hu. 2018. Eye Fatigue Assessment Using Unobtrusive Eye Tracker. *IEEE Access* 6 (2018), 55948–55962. https://doi.org/10.1109/ACCESS.2018.2869624

Elliott Wen and Gerald Weber. 2018. SwiftLaTeX: Exploring Web-based True WYSIWYG Editing for Digital Publishing. In *Proceedings of the ACM Symposium on Document Engineering 2018 (DocEng '18)*. ACM, New York, NY, USA, Article 8, 10 pages. https://doi.org/10.1145/3209280.3209522

Janet Wesson, Dieter Vogts, and Ivan Sams. 2012. Exploring the Use of a Multi-touch Surface to Support Collaborative Information Retrieval. In *Proceedings of the South African Institute for Computer Scientists and Information Technologists Conference (SAICSIT '12)*. ACM, New York, NY, USA, 286–294. https://doi.org/10.1145/2389836.2389870

Seunghyun Woo, Hyojin Suh, and Hosang Cheon. 2012. Reinforcement of Spatial Perception for Stereoscopic 3D on Mobile Handsets. In *CHI '12 Extended Abstracts on Human Factors in Computing Systems (CHI EA '12)*. ACM, New York, NY, USA, 2075–2080. https://doi.org/10.1145/2212776.2223755

Peggy Wright, Diane Mosser-Wooley, and Bruce Wooley. 1997. Techniques and Tools for Using Color in Computer Interface Design. *XRDS* 3, 3 (April 1997), 3–6. https://doi.org/10.1145/270974.270976

Fabrizio Zeri and Stefano Livi. 2015. Visual discomfort while watching stereoscopic three-dimensional movies at the cinema. *Ophthalmic and Physiological Optics* 35, 3 (2015), 271–282. https://doi.org/10.1111/opo.12194

Shumin Zhai, Carlos Morimoto, and Steven Ihde. 1999. Manual and Gaze Input Cascaded (MAGIC) Pointing. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '99)*. ACM, New York, NY, USA, 246–253. https://doi.org/10.1145/302979.303053

Lei Zhang, Xiaopei Wu, Xiaojing Guo, Jingfeng Liu, and Bangyan Zhou. 2019b. Design and Implementation of an Asynchronous BCI System With Alpha Rhythm and SSVEP. *IEEE Access* 7 (2019), 146123–146143. https://doi.org/10.1109/ACCESS.2019.2946301

Sinan Zhang, Akiyoshi Kurogi, and Yumie Ono. 2019a. VR Sickness in Continuous Exposure to Live-action 180°Video. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE, 1269–1270. https://doi.org/10.1109/VR.2019.8798136

Yun-Hong Zhang, Ying-Bao Yang, Tai-Jie Liu, Yi-Lin Chen, and Chao-Yi Zhao. 2017. Comparative Study on Visual Fatigue and Comfort of Different Types of Polarized Light LCD Mobile Phone Screen. In *Proceedings of the 2017 International Conference on Wireless Communications, Networking and Applications (WCNA 2017)*. ACM, New York, NY, USA, 110–115. https://doi.org/10.1145/3180496.3180616