Digital Eye Strain: Investigation and Optometric Management

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July 2023

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Doctor of Optometry 2023

Digital eye strain (DES) is a condition encompassing visual and ocular symptoms that may arise due to the prolonged use of digital devices. The 2023 Tear Film Ocular Surface Lifestyle report defined DES as "the development or exacerbation of recurrent ocular symptoms and / or signs related specifically to digital device screen viewing". Studies vary as to the prevalence of DES with some reporting values as low as 10 % and some reporting values over 90 %.

This programme of research was centred around the identification and management of DES with a focus on Ireland and the UK. The attitudes of optometrists to DES were investigated. Optometrists considered DES to be a significant issue and one that they felt confident in dealing with. Optometrists typically underestimated the prevalence of DES (median at 25 %) compared to previous reports in the literature. Advising on frequent breaks, ocular lubricants and workstation / device set up were the most important management considerations. There were mixed views on specialist spectacle lenses for DES, particularly 'blue filtering' designs, although a significant proportion (34.7 %) did indicate that they recommended these.

DES in working age adults in Ireland and the UK was examined for the first time. Using the Computer Vision Syndrome Questionnaire (CVS-Q), 62.6 % of participants were classified as DES sufferers. There was a very weak correlation between hours of device use and having CVS-Q ≥6 (r_s=0.155, r_s^2=0.024, p=0.001). Fewer than 10 % reported that symptoms were so bad that they affected their work.

Given the increase in digital device use in older adults (≥60 years), this programme of research examined the syndrome in this age cohort for the first time. In a cohort drawn from community optometry practice, significant daily durations of device use were found (median 4 hours) and 51.6 % were found to have DES. There was a strong correlation (r_s=0.81, r_s^2=0.6561, p<0.00001) between dry eye symptoms and DES. The test-retest repeatability of the CVS-Q in an older population was found to be good and a minimum clinically important difference of 1.96 was determined.

Key words: Optometry, Computer Vision Syndrome, Digital Eye Strain, Older Adults, UK, Ireland

Table of contents

Chapter 1: Introduction

1.0 General Introduction 10

1.1 Definition of Digital Eye Strain 11

1.2 Use of Digital Devices 11

1.3 Prevalence and Symptoms of Digital Eye Strain 14

1.3.1 Symptoms of Digital Eye Strain 17

1.4 Detection of Digital Eye Strain 23

1.4.1 Questionnaires 23

1.4.2 Objective Detection of Digital Eye Strain 26

1.4.3 Contributory Factors and Management of Digital Eye Strain 31

1.5 Conclusion 39

1.6 Rationale 40

Chapter 2: Attitudes of Optometrists in the UK and Ireland to Digital Eye Strain and Approaches to Assessment and Management

2.1 Introduction 42

2.2 Methods 42

2.3 Results 46

2.4 Discussion 52

2.5 Conclusion 57

Chapter 3: Digital Eye Strain and its Impact on Working Adults in the UK and Ireland

3.1 Introduction 59

3.2 Methods 60

3.3 Results 64

3.4 Discussion 75

3.5 Conclusion 83

Chapter 4: Digital Eye Strain and Clinical Correlates in Older Adults

4.1 Introduction 84
4.2 Methods 85
4.3 Results 87
4.4 Discussion 94
4.5 Conclusion 100

Chapter 5: Repeatability of the CVS-Q in the Detection and Quantification of Digital Eye Strain in Older Adults

5.1 Introduction 101
5.2 Methods 104
5.3 Results 105
5.4 Discussion 110
5.5 Conclusion 113

Chapter 6: Conclusion

6.1 General Conclusion 114
6.2 Evaluation of experimental work and limitations 116
6.3 Future work 117
6.4 Concluding statement 118

References 119

Appendices:

A	Supporting Documentation	158
B	Ethics Committee Approval Form Study 1	159
C	Ethics Committee Approval Form Study 2	160
D	Ethics Committee Approval Form Studies 3 and 4	161
E	Survey for Study 1	162
F	Survey for Study 2	166
G	Survey for Study 3	172
H	Survey for Study 4	173
I	5 Item Dry Eye Questionnaire (DEQ 5)	174
J	Computer Vision Syndrome Questionnaire (CVS-Q)	175

Abbreviations

AC/A	Accommodative convergence / accommodation
AMD	Age-related macular degeneration
AOI	Association of Optometrists Ireland
BBC	British Broadcasting Company
BLFL	Blue light filtering lenses
BMI	Body mass index
CA	California
CFF	Critical flicker fusion frequency
CI	Confidence interval
Cm	Centimetre
COVID-19	Corona virus disease 2019
CRT	Cathode ray tube
CSO	Central Statistics Office
CVS	Computer vision syndrome
CVS-Q	Computer Vision Syndrome Questionnaire
D	Dioptre
DC	Dioptres cylinder
DES	Digital eye strain
DEQ-5	5 item Dry Eye Questionnaire
DEWS	Dry Eye Workshop
DS	Dioptres spherical
DSE	Display screen equipment
GDPR	General Data Protection Regulation
HSE	Health and Safety Executive
Hz	Hertz
ICC	Interclass correlation coefficient
IOL	Intraocular lens
IQR	Interquartile range
K-S	Kolmogorov-Smirnov
LCD	Liquid crystal display

LED	Light emitting diode
LogMAR	Logarithm of the Minimum Angle of Resolution
MCID	Minimum clinically important difference
NPC	Near point of convergence
Ofcom	Office of Communications
ONS	Office of National Statistics
OSDI	Ocular Surface Disease Index
PIS	Participant information sheet
PUFA	Polyunsaturated fatty acid
RC	Coefficient of repeatability
SD	Standard deviation
Sxs	Symptoms
TBUT	Tear break up time
TFF	Threshold for flicker fusion
TU Dublin	Technological University Dublin, Ireland
UK	United Kingdom
USA	United States of America
VDT	Visual display terminal
VDTS	Visual display terminal syndrome
VFS	Visual fatigue scale
TFOS	Tear Film and Ocular Surface Society

Figures / Tables

Chapter 1: Introduction

Table 1.1: Average daily time spent online by UK adults aged 16 years and older 13

Table 1.2: Percentage of UK adults using digital devices by age group 13

Table 1.3: Average prevalence rates of studies into digital eye strain by country 15

Table 1.4: Main categories of symptoms in digital eye strain as categorised by Blehm et. al (2005) 17

Table 1.5: Symptoms associated with digital device use as categorised by Sheedy et. al (2003) 18

Chapter 2: Attitudes of Optometrists in the UK and Ireland to Digital Eye Strain and Approaches to Assessment and Management

Table 2.1: Summary of 22 item digital eye strain questionnaire for optometrists in the UK and Ireland 43

Table 2.2: Number of years registered as an optometrist and main practice setting of respondents 45

Table 2.3: Attitudes towards digital eye strain 44

Figure 2.1: Practitioner perceptions of the proportion of patients attending their clinic who they believe are affected by digital eye strain 46

Table 2.4: Key symptoms of digital eye strain cited by optometrists 47

Figure 2.2: Frequency of asking questions regarding digital device usage during routine case history 48

Figure 2.3: Respondents' perceptions of the importance of advising patients on various management options for digital eye strain 50

Chapter 3: Digital Eye Strain and its Impact on Working Adults in the UK and Ireland

Table 3.1: Summary of the 41-item questionnaire for adult device users in Ireland and the UK 61
Table 3.2: Age of respondents 62
Table 3.3: Respondents digital device usage – type and daily duration 63
Figure 3.1: Occurrence of symptoms as reported on the DEQ-5 questionnaire on a typical day during the last month 65
Figure 3.2: Percentage of participants by age band (years) with a CVS-Q ≥6 66
Figure 3.3: Percentage of participants selecting each symptom type on CVS-Q 67
Figure 3.4: Correlation between participants DEQ-5 and CVS-Q scores 68
Figure 3.5: Scale of 1 to 10 on how bothersome symptoms were when reported by participants 70
Figure 3.6: Scatter plot of bother score of ocular symptoms and CVS-Q score of participants 71

Chapter 4: Digital Eye Strain and Clinical Correlates in Older Adults

Table 4.1: Percentage of participants which used different device types 87
Table 4.2: Symptoms experienced when using digital devices 86
Figure 4.1: Correlation between participants DEQ-5 scores and hours of device use 87
Figure 4.2: Occurrence of symptoms as reported on the DEQ-5 questionnaire on a typical day during the last month 89
Figure 4.3: Correlation between participants CVS-Q scores and hours of device use 90
Figure 4.4: Percentage of participants selecting each symptom on CVS-Q 91
Figure 4.5: Correlation between participants DEQ-5 and CVS-Q scores 92

Chapter 5: Repeatability of the CVS-Q in the Detection and Quantification of Digital Eye Strain in Older Adults

Table 5.1: Previously published studies which used the CVS-Q 99
Figure 5.1: Correlation between CVS-Q1 and CVS-Q 2 score 105
Figure 5.2: Bland Altman plot of the mean CVS-Q score for each participant

across the two CVS-Q completions 106
Table 5.2: McNemar test *p* values for each of the 16 symptoms of the CVS-Q 107
Figure 5.3: Comparison of the percentage of participants selecting each symptom when completing the CVS-Q2 and CVS-Q1 108

CHAPTER 1
INTRODUCTION

1.0 General Introduction

The use of desktop, laptop and tablet computers as well as ‘smart’ mobile / cellular phones is almost universal in today’s world. Managing any type of discomfort that may inhibit the capability of the user to view these devices is essential. Failure to do so could have an impact on their ability to work, meet their educational needs and socialise with friends and family. The COVID-19 pandemic has resulted in an increase in the amount of time spent viewing screens with the result that more individuals are likely to be experiencing difficulties when viewing their devices (Sultana *et al.*, 2021; Almalki *et al.*, 2023; Chattinnakorn *et al.*, 2023). Therefore, it is likely that optometrists will see an increasing number of patients attending their practices who are experiencing difficulties using their digital devices.

Health and safety regulations in the UK and Ireland require employers to provide eye care to their workers who use a digital screen for more than 1 hour per day, this includes provision of an eye examination and spectacles if needed when using the device. Employers are also required to analyse workstations so as to make them as comfortable and safe as possible for their employees (Health and Safety Executive, 2003; Health and Safety Authority, 2005). However, little is known as to how optometrists manage these patients and their attitude to them and to their symptoms. Additionally, no published studies have been done in Ireland or the UK to determine how many people experience problems when using their devices and to what extent it affects them. Studies are also lacking as to how the older population are affected by these problems, and whether they will suffer similar or different issues when using their devices. According to the Central Statistics Office (CSO) of Ireland, the over 60s currently account for 18.2 % of the Irish population and this is expected to increase to 28.3 % by 2051, and according to the Office for National Statistics (ONS) of the UK, the over 60s currently make up 21.7 % of the UK population and again this is expected to rise to 25.4 % by 2041. As such more research is needed into the effects of DES in this increasingly growing age cohort.

The aim of this research study is to answer these questions, to see how these patients are managed by their optometrist, to determine the extent of the problem in Ireland and the UK and to look at how the problem affects the older population specifically and to see if the instruments used to detect the condition are useful and reliable in this age cohort.

1.1 Definition of Digital Eye Strain

Digital Eye Strain (DES), also referred to as Computer Vision Syndrome (CVS) or less frequently, Visual Display Terminal Syndrome (VDTS), describes the collection of visual, ocular and musculoskeletal (neck and shoulder pain) symptoms that may result from prolonged use of computers or other digital devices and has been a recognised health problem for over 20 years (Wiggins and Daum, 1991; Rosenfield, 2011; Portello *et al.*, 2012; Gowrisankaran and Sheedy, 2015; Sheppard and Wolffsohn, 2018; Zayed *et al.*, 2021). Digital Eye Strain is the preferred term as many people do not consider devices such as smart phones, tablets, e-readers to be computers (Rosenfield, 2016). According to the American Optometric Association, DES encompasses a cluster of ocular and vision-related problems attributed to prolonged usage of desktops, laptops, mobile phones (including smart phones), tablets, e readers and storage devices.

1.2 Use of Digital Devices

The use of various digital devices has become ubiquitous amongst all age groups with the typical digital consumer owning around four devices (Coles-Brennan *et al.*, 2019) and the average American adult now has access to at least 10 digital devices (Wolffsohn *et al.*, 2023). According to the Office for National Statistics (ONS) in 2020, 96 % of UK households had access to the internet and 89 % of adults used the internet at least once a week. The majority of adults and children spend significant amounts of time using digital devices, for social activities, work and increasingly education (Chen and Adler, 2019; Madigan *et al.*, 2019; Zayed *et al.*, 2021; Chattinnakorn *et al.*, 2023). In recent years, the use of hand-held electronic devices, such as smartphones, tablets and e-readers, has increased substantially (Long *et al.*, 2017; Choi *et al.*, 2018); these devices present different visual challenges compared to desktop or laptop computers. Unlike traditional desktop computers, tablet computers and other hand-held devices can be used at different viewing distances and angles and often require smaller font sizes because of the reduced screen size, which imposes significant demands on the visual system (Jaiswal *et al.*, 2019). Furthermore, hand-held electronic displays, such as e-readers, may be associated with greater risk of discomfort from improper lighting (Long *et al.*, 2017). In addition, accommodation is altered with handheld device use, with increased lag and decreased amplitude; smartphone and tablet use results in reduced fusional convergence and possibly a receded near point of convergence (Ha *et al.*, 2014; M. Park *et al.*, 2014; Jaiswal *et al.*, 2019).

Since the onset of the COVID-19 pandemic in early 2020, prevalence of DES may have increased because of the extensive use of digital devices for home working (where workstations designed for comfortable computer use may not be available), entertainment activities and tasks such as home shopping (Pišot *et al.*, 2020; Vargo *et al.*, 2020; Sultana *et al.*, 2021; Almalki *et al.*, 2023; Chattinnakorn *et al.*, 2023). In addition, the pandemic resulted in large swathes of all levels of education shifting from face-to-face to online, further increasing the use of digital devices and the risk of DES. It is estimated that the prevalence of DES in children rose from about 18 % before the pandemic (Ichhpujani *et al.*, 2019) to 50 – 60 % during the pandemic (Mohan, Sen, Shah, Jain, *et al.*, 2021; Demirayak *et al.*, 2022; Kaur *et al.*, 2022) and symptoms in children expanded to include recent onset esotropia and vergence abnormalities (Mohan, Sen, Mujumdar, *et al.*, 2021; Mohan, Sen, Shah, Datt, *et al.*, 2021). Furthermore many 'lockdown' measures restricted outdoor activities which may have resulted in new onset myopia and increased progression of existing myopia becoming an ocular health complication of DES (Wang, Li, *et al.*, 2021; Kumari *et al.*, 2022; Mohan *et al.*, 2022). In their 2021 study McCrann *et al.* demonstrated an association between myopia and smartphone use in primary, secondary and tertiary level students. Harrington and O'Dwyer (2023) reported that increased screen time in children was associated with increased body weight and body mass index (BMI) and decreased reading and writing time.

The UK Office for Communications (Ofcom) reported that in April 2020, during the height of the first COVID-19 lockdown, UK adults typically spent a daily average of 4 hours and 2 minutes online up from 3 hours 29 minutes in September 2019, in September 2021 they reported UK adults spent 3 hours and 59 minutes online every day and in July 2022 they reported UK adults typically spent 4 hours online every day (see table 1.1 below). A post-pandemic Turkish study in 2022 found that in many cases total screen time was 4.5 hours (Konca, 2022). In Ireland, a 2020 survey by Irish market research company Ipsos MRBI found that 84 % of adults used a smartphone and 80 % used a laptop or desktop computer, 34 % of respondents spend more than 4 hours per day on their smartphone and 24 % spend more than 4 hours per day on their computer (Gibney and McCarthy, 2020).

The proportion of UK adults making online video calls doubled during the first COVID-19 lockdown, with more than 7 out of 10 adults doing so at least weekly (Ofcom, 2020, 2021). The video calling trend was particularly noticeable in older internet users (adults aged 65 years and older) with the number who made at least one video call a week increasing from 22 % in February 2020 to 61 % in May 2020. However, little appears to be known about the effects of prolonged device use in this age group. During this same period ‘Zoom’, a virtual meeting platform, grew from 659,000 adult users in the UK in January 2020 to over 13 million in April 2020 (Ofcom, 2020). The use of ‘Zoom’ and similar applications (such as ‘Facetime’, Microsoft ‘Teams’) does not usually require simultaneous reading from the screen and is therefore more passive and less intense, therefore symptoms of DES may be less with this type of screen use. The report also revealed that 32 % of UK adults spend more time viewing video sharing services than broadcast television, with 18–24-year-olds spending the most time online (an average of 5 hours 4 minutes per day in April 2020). In general the average UK adult spends 40 % of their waking time viewing digital screens (Ofcom, 2020).

Period	Average Daily Time Spent Online
September 2018	3 hours 11 minutes
September 2019	3 hours 29 minutes
April 2020	4 hours 2 minutes
September 2021	3 hours 59 minutes
July 2022	4 hours

Table 1.1: Average daily time spent online by UK adults aged 16 years and over (Ofcom, 2020, 2021, 2022b, 2023).

In their 2021 report, Ofcom found that the device type used by age differs, as shown in table 1.2 below.

Age (years)	Smartphone (%)	Laptop (%)	Tablet (%)	Smartwatch (%)
16 to 24	99	83	76	44
25 to 34	98	80	71	36
35 to 54	96	73	59	28
55 to 64	89	58	40	16
65 and over	73	31	18	5

Table 1.2: Percentage of UK adults using different digital devices by age group (Ofcom, 2021)

1.3 Prevalence and Symptoms of Digital Eye Strain

The prevalence of DES is high, typically 50% or more (Portello *et al.*, 2012; Tauste *et al.*, 2016; Coles-Brennan *et al.*, 2019; Zayed *et al.*, 2021) although some research has suggested that it may be even higher, at between 64 % and even 99 % of computer workers (Hayes *et al.*, 2007; Yan *et al.*, 2008; Ahuja *et al.*, 2021; Noreen *et al.*, 2021; Zayed *et al.*, 2021). Differences in reported prevalence are likely because of the absence of definitive methods of diagnosis and assessment, i.e., each study used their own criteria. To diagnose DES some studies relied solely on the existence of one or more symptoms of DES without connecting these to the length of screen / device use or the long-term frequency of these symptoms and therefore may have exaggerated the true prevalence of DES (Iqbal, Elzembely, *et al.*, 2021; Iqbal, Said, *et al.*, 2021). The condition may cause frequent and persistent symptoms for sufferers and may even reduce productivity among employees who use devices for many hours a day (Wilkinson and Robinshaw, 1987; Daum *et al.*, 2004; Wolffsohn *et al.*, 2023). In some cases, symptoms can be so severe that they impact the quality of life of those affected (Hayes *et al.*, 2007; Sheppard and Wolffsohn, 2018).

The prevalence of DES has been shown to differ widely from country to country and even within countries. Anbesu and Lema (2023) conducted a systemic review and meta-analysis of 45 studies examining the worldwide prevalence of DES and found that the prevalence rate varied from as low as 11.6 % in Japan to as high as 98.7 % in Pakistan (the pooled global prevalence rate was 66 %). Seven studies in India showed rates as high as 86.7 % and as low as 32.3 %, seven Ethiopian studies showed rates as high as 81.3 % and as low as 68.8 %, three studies in Spain showed rates as high as 76.6 % and as low as 56.7 %. This again demonstrates the need for a more consistent way to diagnose DES. It should be noted that no studies considered in this review were conducted in the Ireland or the UK, revealing a deficit in the knowledge regarding DES in this region. Table 1.3 below shows the average prevalence rate of DES in the countries considered in Anbesu and Lema's 2023 review.

Country	Average prevalence (range) %	Number of studies
India	65.12 (32.3 – 86.70	8
Ethiopia	73.32 (68.8 – 81.3)	7
Saudi Arabia	67.6 (43.5 – 95.1)	4
Pakistan	63 (28.0 -98.7)	4
Egypt	80.66 (75.0 -84.8)	3
Spain	69.2 (56.7 – 76.6)	3
Ghana	62.36 (51.5 – 64.4)	3
China	65.67 (57.0 – 74.3)	2
Nigeria	59.65 (54.2 – 65.1)	2
Brazil	39.65 (24.7 – 54.6)	2
Jordan	94.5	1
Nepal	82.5	1
Thailand	81.02	1
Lebanon	67.8	1
Sri Lanka	67.4	1
Iran	49.4	1
Japan	11.6	1

Table 1.3: Average prevalence rates of studies into DES by country arranged by number of studies and prevalence rate (Anbesu and Lema, 2023).

Over the last three decades numerous studies have evaluated the severity and frequency of symptoms associated with the use of computers in the workplace. A

1996 survey of computer users versus non-users showed that visual complaints were reported by 75 % of computer users who worked 6 – 9 hours per day in front of their screens compared to 50 % of non-users (Mutti and Zadnik, 1996). In 2008, a survey of 419 computer users in India reported that 46.3 % of the users experienced two or more symptoms of DES either during or after computer work (Bhanderi *et al.*, 2008). More recently, DES was also reported in over 50 % of call centre computer workers in Sao Paulo, Brazil (Sa *et al.*, 2012), in 62.4 % of adults working in administration in India (Ahuja *et al.*, 2021) and in over 80 % of information technology professionals in Egypt (Zayed *et al.*, 2021). It would be beneficial if studies used a recognised and validated instrument for the diagnosis of DES to make the results more comparable, however such instruments are uncommon.

DES is significantly influenced by the visual demand and duration of the task, severity is especially dependent on the time spent on the task and increases significantly with longer device use (Travers and Stanton, 1984; Bergqvist *et al.*, 1992; Coles-Brennan *et al.*, 2019; Omran Al Dandan *et al.*, 2020; Talens-Estarelles *et al.*, 2021; Venkateshvaran *et al.*, 2023). Rossignol *et al.* (1987) found that those who spent more than 4 hours working at a computer experienced greater incidence of symptoms. In 2012, a significant link between reported symptoms and the number of hours spent working on a computer was discovered in a study of 520 office workers in the United States (Portello *et al.*, 2012); this study also found a higher prevalence of DES in females, a finding that was replicated in the 2016 'Digital Eye Strain Report', 69 % of females reported symptoms as opposed to 60% of males (Vision Council, 2016), although it should be noted that this latter study was not subjected to peer review. It is possible that this difference could be linked to the different prevalence of dry eye between the sexes (Guillon and Maïssa, 2010; Courtin *et al.*, 2016; Craig, Nelson, *et al.*, 2017). Dry eye and the ocular surface are discussed further below.

Contact lens wearers also appear to be more susceptible to DES (Wiggins *et al.*, 1992; Tauste *et al.*, 2016) as are computer workers who have dry eyes (Tsubota and Nakamori, 1993). In a survey of optometrists, Sheedy (1992) showed that 14.5 % of patients booked an eye examination because of problems working with computers or other digital devices. Contact lens use and refractive error and their significance in DES is discussed further in the following section.

1.3.1 Symptoms of Digital Eye Strain

Symptoms reported by users of digital devices include eye strain, eye fatigue, burning and irritation of the eyes, headache, tired eyes, dry eyes, ache in and around the eyes, blurred vision at near, blurred vision when looking from near to distance, neck ache and shoulder pain (Wilkinson and Robinshaw, 1987; Dain *et al.*, 1988; Sheedy, 1992; Costanza, 1994; Daum *et al.*, 2004; Jaiswal *et al.*, 2019). Transient blindness was also mentioned as a symptom by Blehm *et al.* (2005) although this has not been widely reported in the literature surrounding DES; it is thought the phenomenon occurs due to bleaching of the photo pigment in the retina and rapid shifts from light adaptation to dark adaptation and vice versa.

In most cases, the symptoms of DES are mild and transient, but they can be persistent and frequent (Wilkinson and Robinshaw, 1987; Daum *et al.*, 2004). It has been reported that the extent to which a user may experience symptoms is dependent on their visual ability in relation to the visual demands of the task being performed with symptoms being more pronounced in those with reduced visual ability (Munshi *et al.*, 2017). Moreover duration of device use (Portello *et al.*, 2012), form of visual correction, i.e. spectacles / contact lenses or specific computer spectacles (Horgen *et al.*, 2004; Chalmers and Begley, 2006), sex (Hayes *et al.*, 2007; Mehra and Galor, 2020), and ocular surface status (Mobeen *et al.*, 2016; Jaiswal *et al.*, 2019) have been shown to be related to the presence and severity of symptoms. Prolonged exposure to high energy short wavelength ‘blue light’, which is emitted from many digital devices, has been suggested to induce eye strain (Lawrenson *et al.*, 2017) and night-time exposure may alter sleep patterns (Dijk and Archer, 2009). The subject of ‘blue light’ in DES is discussed further below.

Attempts have been made to categorise the wide range of DES symptoms. Blehm *et al.* (2005) classified the symptoms of DES into four main categories: asthenopic, ocular surface related, visual and extra-ocular (as shown in table 1.4).

Symptom Category	**Symptoms**	**Possible Causes**
Asthenopic	Eye strain Tired eyes, sore eyes	Binocular vision or accommodation dysfunction
Ocular surface related	Dry eyes Watery eyes Irritated eyes Contact lens problems	
Visual	Blurred vision Slowness of focus change Double vision Presbyopia	Refractive error Accommodation or binocular vision dysfunction
Extra ocular	Neck pain Back pain Shoulder pain	Computer / digital device screen location

Table 1.4: Main categories of symptoms in DES as categorised by Blehm *et al.* (2005).

Sheedy *et al.* (2003) classified symptoms into ocular (internal and external), visual and musculoskeletal (as shown in table 1.5).

Ocular symptoms	**Visual Symptoms**	**Musculoskeletal Symptoms**
Internal Strain Ache in the eyes Ache around eyes Tired eyes Eyestrain Sore eyes *External* Burning Irritation	Blurred vision (at near) Blurred vision (when looking from near to far) Double vision	Neck ache Shoulder pain

Dryness Redness		

Table 1.5: Symptoms associated with digital device use as classified by Sheedy *et al.* (2003).

Both of these classifications are in broad alignment; however, Sheedy *et al*. (2003) grouped internal and external symptoms together into ocular symptoms while Blehm *et al.* (2005) recorded them separately, again highlighting inconsistencies in the definition and diagnosis of DES. It should also be noted that although musculoskeletal symptoms are included in both of these classifications, not all studies of DES have considered these effects, many concentrating only on ocular symptoms (Chu *et al.*, 2011; Portello *et al.*, 2012; Omran Al Dandan *et al.*, 2020; Sánchez-Brau *et al.*, 2021).

Although symptoms such as eye fatigue, ache in and around the eyes, blurred vision and headache have also been reported in workers performing intensive non-computer / digital device tasks, the symptoms experienced immediately after a sustained near task performed on a digital device have been found to be greater than those experienced following a similar paper-based task (Chu *et al.*, 2011). It is possible that this may be because the eyes perceive images on a digital device or printed paper differently; Jaschinski *et al.* (1996) suggested that images on a digital device are in fact blurred and lack sharp edges unlike on printed paper, however they are not seen as blurred because of the rate at which they are refreshed or rewritten on the screen by the device. However, since this latter study was published digital device screens have improved with very high refresh rates, (averaging at 60 times a second (i.e. 60Hz) but can be as high as 300 times a second, making them essentially flicker free), higher display resolution and higher background luminance which will help to improve visual comfort for the user (Menozzi *et al.*, 2001; Haynes, 2022). Screen quality and refresh rates are discussed in more detail below.

Taking adequate breaks from digital devices is believed to have a dramatic effect in controlling the symptoms of DES as well as improving work efficiency (Misawa *et al.*, 1984; Izquierdo *et al.*, 2007). However, Reddy *et al.* (2013) reported that taking breaks by itself was not associated with reduced symptoms whereas looking at far objects during a break was. The 20/20/20 strategy, where after 20 minutes of screen use the user looks at objects 20 feet away for 20 seconds, is a popular recommendation and is frequently recommended by optometrists in practice (Tribley *et al.*, 2011; Reddy *et al.*, 2013; Jones *et al.*, 2016) and by organisations such as the American Optometric Association (2017) and the American Academy of Ophthalmology (2021) and indeed Talens-Estarelles *et al.* (2022) found the 20/20/20 rule is an effective strategy for reducing DES and dry eye symptoms in device users.

Dry eyes are a common symptom of DES; this may be attributed to a reduced blink rate and / or incomplete blinking which has been shown to occur during screen use and can lead to poor tear film quality (Tsubota and Nakamori, 1993; Kim *et al.*, 2020). Decreased and incomplete blinking and tear evaporation while using digital devices causes ocular surface changes and can result in sore and tired eyes (Portello *et al.*, 2013; Choi *et al.*, 2018). Using a topical lubricant has been shown to be effective on countering the issues of dry eyes (Toda *et al.*, 1993; Tsubota and Nakamori, 1993; Portello *et al.*, 2012). The topic of dry eye and ocular surface is discussed further below.

Contact lens wearers have been found to be significantly more likely than non-wearers to suffer from dry eye symptoms when using digital devices (Chalmers and Begley, 2006; González-Méijome *et al.*, 2007; Kojima *et al.*, 2011; Tauste *et al.*, 2016). González-Méijome *et al.* (2007) reported that 83 % of male and 87 % of female contact lens wearers had at least one dry eye symptom compared to 68 % of male and 73 % of female non wearers; symptoms were more prominent in the contact lens wearers who used computers for between 3 and 6 hours than those who used one for fewer hours. Females reported more scratchiness than males among both non-contact lens users ($p = 0.029$) and contact lens users ($p = 0.008$). Tauste *et al.* (2016) found that workers who wore contact lenses and used a computer for > 6 hours per day were more likely to suffer from DES than non-contact lens wearers. Female contact lens users also had a higher prevalence of symptoms at the end of the working day than males ($p < 0.001$). Chalmers and Begley (2006) reported a higher prevalence of dry eye symptoms in contact lens users but did not find any difference between genders and symptoms were relieved when contact lenses was removed. Other studies have reported a higher prevalence of dry eyes and contact lens related dryness in females, especially when using digital displays /

screens (Wiggins and Daum, 1991; Paulsen *et al.*, 2014; Mehra and Galor, 2020). Contact lens comfort is dependent on the correct fitting of the lens and good ocular surface lubrication, the lens should move on the eye with minimal resistance (Young *et al.*, 2017; Siddireddy *et al.*, 2018). However, if the ocular surface is dry, the lens will adhere to the upper eyelid when blinking, resulting in discomfort for the wearer (Wiggins *et al.*, 1992; Siddireddy *et al.*, 2018). In 2010, it was reported that concentrated tasks on digital devices in established contact lens wearers resulted in a reduced blink rate and amplitude, drying the lens and the ocular surface (Jansen *et al.*, 2010).

Uncorrected or inappropriately corrected refractive error can contribute to symptoms of DES (Sheedy and Parsons, 1990; Gowrisankaran *et al.*, 2007; Nahar *et al.*, 2007; Rosenfield *et al.*, 2012). Uncorrected astigmatism appears to be especially problematic with reports that between 0.50 D and 1.00 D of uncorrected astigmatism can cause significant subjective visual discomfort (Wiggins and Daum, 1991; Wiggins *et al.*, 1992), while 1 to 2 D of uncorrected astigmatism can increase task errors and can reduce worker productivity by up to 28.7 % (Daum *et al.*, 2004). The use of handheld digital devices has become ubiquitous in society and individuals of all ages are increasingly using these devices for many aspects of daily life (Madigan *et al.*, 2019). Because of the decline in accommodation with increasing age, people of different ages may experience different problems when using handheld devices (Mylona and Floros, 2022). The physiological mechanisms that underlie DES symptoms related to uncorrected refractive error are not well understood with Mylona and Flores (2022) finding that the correction of presbyopia alone did not adequately protect against DES when using handheld devices. Possible involvement of the orbicularis oculi muscle because of the eyelid squint response to the uncorrected refractive error has been suggested (Sheedy, Truong, *et al.*, 2003; Gowrisankaran *et al.*, 2007). Therefore, it is imperative that the refractive error be appropriately corrected for the task(s) being performed by the user and this would be of even greater importance in a presbyopic user.

Lighting is a significant environmental factor that can affect vision when using digital devices and lead to the onset of symptoms (Chang *et al.*, 2013; Lin *et al.*, 2019). Optimal lighting is achieved when the visual field has a uniform distribution of luminance. Improper lighting conditions, such as glare from windows or overhead lights and reflections from walls, ceilings and computer screens, results in a field of view with objects that have large differences in brightness; unequal luminance between the immediate background and the display screen causes discomfort glare (Gowrisankaran and Sheedy, 2015). In addition because of age-related changes in the ocular media, users over 50 years of age may require increased illumination when viewing a screen compared to the illumination needed by younger users (Werner *et al.*, 1990; Munshi *et al.*, 2017; Sánchez-Brau *et al.*, 2020). Light reflected from the screen is equally important because peripheral lighting can cause glare (Dain *et al.*, 1988, p. 19; Collins *et al.*, 1990). Two main types of glare are recognised, discomfort glare and disability glare. Coles-Brennan *et al.* (2019) described discomfort glare as the temporary irritation caused by light and may be a response to the saturation of visual neurons; disability glare is the temporary impairment of vision caused by light and can occur independently of discomfort glare because it is caused by the loss of retinal image contrast that results from intraocular light scatter. Glare which is commonly experienced by screen users (Dain *et al.*, 1988; Collins *et al.*, 1990) has been found to cause a reduction in reading speed (Garciai and Wierwille, 1985) and may be a major cause of DES (JE, 2003; Thorud and Helland, 2012; Mork *et al.*, 2016). The source of glare can be light from the display screen or from the environment (Hultgren and Knave, 1974; Goodwin, 1987; Berman *et al.*, 1991; Hedge *et al.*, 1995). Glare from surrounding lighting may have a negative effect on accommodation (Wolska and Śwituła, 1999; Wolska, 2019). The brightness of the screen and that of the working environment should be balanced. Filters can be used to reduce glare and reflections from the screen but they should be used as a supplement and not as a replacement solution because filters do not lessen occurrences of asthenopia (Gumener *et al.*, 1996). The colour of the characters on the screen is also a consideration. Black characters on a white background have been found to be more comfortable for users than coloured characters (Murch, 1982).

Given the high prevalence of the syndrome, optometrists in general practice are likely to be consulted by patients suffering from DES and should be able to give relevant clinical and practical advice to patients who present such symptoms.

1.4 Detection of Digital Eye Strain

1.4.1 Questionnaires

Several instruments have been developed to aid in the diagnosis of DES. Notably these instruments have been developed and employed predominantly amongst computer workers (because of this cohorts long hours of work related computer use). The instruments have not typically been developed with the public despite long hours of computer or digital device use being commonplace for most adults (Coles-Brennan *et al.*, 2019) nor have they been used to study the impact of DES on older adults who are increasingly using digital devices.

Hayes *et al.* (2007) used a bespoke 10-point questionnaire to calculate a total DES symptom score in computer workers. The questionnaire was used to model the effects of computer use on reported visual and physical symptoms and to measure the effects upon quality-of-life measures. Respondents averaged 6 hours per day using the computer. Hayes *et al.* (2007) reported that there was a definite correlation between the presence of DES symptoms and quality of life and physical symptoms. There was no association between symptoms and the participants age or gender. When adjusted for age, gender, ergonomics, hours using the computer and exercise, eye symptoms were significantly associated with physical symptoms ($p < 0.001$) accounting for 48 % of the variance.

Portello *et al.* (2012) used a multi-section questionnaire, including the ocular surface disease index survey (OSDI), to determine the prevalence of DES in office workers. The results of this survey showed a significant positive correlation with the results of the OSDI, highlighting the significance of the ocular surface in DES. A significant positive correlation was also seen between the symptom score and the number of hours spent working on the device during the day. The most prevalent symptom was tired eyes which was reported by approximately 40 % of respondents as occurring at least half of the time, 32 % reported dry eye and 31 % reported eye discomfort. Symptoms were significantly greater in females than males and in Hispanics than other ethnic groups. The study highlighted the frequent nature of visual symptoms in computer users and demonstrated a strong association between DES and ocular surface disorders.

The Visual Fatigue Scale (VFS), originally developed by s Römer in 1989, uses six questions (on a Likert scale) to determine the presence of DES. With questions relating to numbness and dizziness this scale is quite different to other surveys described, such as Hayes *et al.* (2007) and Portello *et al.* (2012), and as such, results between this instrument and others will not be easily comparable. The VFS has been used to compare symptoms that occurred when using electronic readers with liquid crystal displays (LCD) to symptoms occurring when reading the same text on paper or on an electronic ink type display (Benedetto *et al.*, 2013). Results from both objective (blinks per second) and subjective (VFS) measures suggested that reading on the LCD display type device results in greater visual fatigue that occurs with both the electronic ink display and the paper book. The absence of differences between the electronic ink display and paper suggests that, concerning visual fatigue, the electronic ink is similar to the paper. The VFS was also used in a 2013 study to compare reading performance and visual fatigue using an electronic paper display in a long duration reading task under various lighting conditions (Chang *et al.*, 2013). Results showed that reading speed differed significantly across different electronic paper displays and ambient illuminance levels. The reading speed was slower for displays with smaller screens and increased as the illumination levels increased.

The instruments described above used by Hayes *et al.* (2007), and its modified version by Portello *et al.* (2012), and the VFS have not been validated, although Hayes' instrument was shown to be repeatable (Rosenfield *et al.*, 2012). More recently, del Mar Segui *et al* (2015) designed and validated a questionnaire to 'measure visual symptoms related to exposure to computers in the workplace'. The 'Computer Vision Syndrome Questionnaire (CVS-Q)' assesses the frequency and intensity of 16 symptoms using a single rating scale (symptom severity). The symptoms assessed are listed below:

- Burning
- Itching
- Feeling of a foreign body
- Tearing
- Excessive blinking

- Eye redness
- Eye pain
- Heavy eyelids
- Dryness
- Blurred vision
- Double vision
- Difficulty focusing for near vision
- Increased sensitivity to light
- Coloured halos around objects
- Feeling that sight is worsening
- Headache

Responses are scored using 3-point scales to rate symptom frequency (0=Never, 1=Occasionally, 2=Often or Always) and intensity (0=Never, 1=Moderate, 2=Intense).

Results are calculated using the following equation (which is explained thereafter):

Score = $\sum_{i=1}^{16}(frequency\ of\ symptom\ occurence)i\ x\ (intensity\ of\ symptom)i$

The scores for frequency and intensity are multiplied and then recorded ($0 \rightarrow 0$, 1 or $2 \rightarrow 1$, $4 \rightarrow 2$). The scores are summed to provide a total score out of 32, and if the score is ≥ 6, the worker is considered to suffer from computer vision syndrome. The survey was shown to have good sensitivity, 75 %, and specificity, 70 % and to achieve good test-retest repeatability both for scores and diagnosis. The CVS-Q identifies the occurrence of each particular symptom and the overall symptoms in computer workers so that the results can be compared between different individuals or in the same individual at different times and circumstances. Given the validity and reliability of the CVS-Q, it is a useful instrument for clinical research into DES and its management. It has been used in numerous published studies in the area of DES (as detailed in chapter 5) and while it was designed for 'computer workers' it has been used outside of these requirements (Tauste *et al.*, 2016; Teo *et al.*, 2019; Sánchez-Brau *et al.*, 2020; Zayed *et al.*, 2021; Talens-Estarelles, García-Marqués, *et al.*, 2022) and has even been used as a means to validate other instruments for diagnosing DES in adults aged 18 to 45 years (Mylona *et al.*, 2022).

1.4.2 Objective Detection of Digital Eye Strain

Although instruments such as questionnaires can be used to subjectively determine the presence of DES objective assessment has been investigated. Such assessments do not measure DES symptoms directly but analyse objective correlates which should be less influenced by participant bias. However, some of the assessments may not be suitable for use in general optometric practice because of the specialist equipment or the long examination times required.

Critical Flicker Fusion Frequency

Critical flicker-fusion frequency (CFF) is a recognised measure of fatigue and mental workload (Łuczak and Sobolewski, 2005) and is the frequency at which a flickering light is indistinguishable from a steady, non-flickering light and it is used to assess the processing of temporal vision. The upper level of one's abilities in visual processing is described as the critical flicker fusion threshold (or threshold for flicker fusion, TFF), which represents the maximum speed of flickering light that can be perceived by the visual system. Because of its efficiency in detecting rapid changes, it is used as an index of cerebral nervous system function that is described as alertness and cortical arousal in humans (Mankowska *et al.*, 2021). Lin *et al.* (2017) suggested a decrease in CFF to be an indicator of visual fatigue after a decrease in CFF was measured in computer workers, who also reported symptoms associated with DES and therefore it was suggested that a decrease in CFF could be used as an objective assessment of DES. However, studies in 2022 by Singh *et al.* and Yan *et al.* have since concluded that changes in CFF should not be used as an objective measure of digital eyestrain given its low correlation with scores on a visual fatigue symptom questionnaire.

Blink Rate and Completeness

Blinking helps to maintain a normal and healthy ocular surface with most blinks instigating a cycle of secretion, dispersal, evaporation and drainage of tears (Himebaugh *et al.*, 2009). Blinking can be described as the predominantly involuntary rapid closure of the eyelids, the average blink rate is between 12 and 20 per minute with each blink lasting between 0.1 and 0.4 seconds (Hossain *et al.*, 2022). Impaired blinking disturbs the tear film balance resulting in disruption in tear film structure and the homeostasis of the ocular surface which will in turn lead to ocular discomfort and dry eye (Portello *et al.*, 2013; Choi *et al.*, 2018; Kim *et al.*, 2020). A reduction in blink rate during computer use has been found in many studies (Patel *et al.*, 1991; Tsubota and Nakamori, 1993; Freudenthaler *et al.*, 2003; Hossain *et al.*, 2022) and has been suggested as a possible causative factor in the symptoms of dry eye experienced by device users. The reduction can be substantial with one study reporting a reduction from 22 blinks per minute before computer use to just 7 blinks per minute when viewing a screen (Tsubota & Nakamori, 1993). Portello *et al.* (2013) showed that blink characteristics correlate with symptoms of DES, with a lower blink rate leading to a higher symptom score. Lapa *et al.* (2023) found a reduction in blink rate when using a device to vary between 9 and 17 per minute, and for each additional blink the CVS-Q score lowered by 1.26, suggesting that a decrease in blinking rate was directly associated with DES.

The reduction in blink rate observed when using a digital device could be caused by involuntary squinting that occurs when using a display screen (Sheedy *et al.*, 2005; Gowrisankaran *et al.*, 2007). A drop in blink rate has also been linked to performing tasks with a higher cognitive demand or low-legibility conditions which require a lengthening of fixation duration allowing increased time to acquire and understand the visual information being presented (Gowrisankaran *et al.*, 2007; Hossain *et al.*, 2022; Chidi-Egboka *et al.*, 2023). Furthermore, Rosenfield *et al.* (2015) reported that changing the cognitive demand of a task, displayed on a digital screen and on paper, had a greater effect on reducing blink rate than the method of presentation.

Chu *et al.* (2014) found no difference in blink rate between reading from a digital display and a hard copy of the same text, however there was a much higher rate of incomplete blinking with the digital display. Results showed the blink rate when reading from the computer screen was 14.9 per minute (SD 8.61) and from the printed copy was 13.6 per minute (SD 8.28), but this difference was not significant. However, the percentage of incomplete blinks during the computer screen usage was significantly higher than for the printed copy, 7.02 % and 4.33 % respectively ($p = 0.02$). The study concluded that although there was no significant difference between blink rate when performing the two tasks, there was a more significant difference in blink completeness which may be associated with visual fatigue.

Argiles *et al.* (2015) reported similar findings to those reported by Chu *et al.* (2014). The study reported a significant proportion of incomplete blinks when reading from digital devices when compared to reading on paper, with the highest level of incomplete blinks occurring when reading from a tablet. The study concluded that the higher cognitive demand associated with reading, either from paper or from a digital device, caused a reduction in blink rate from baseline, but only reading from the digital device resulted in a significant increase in the percentage of incomplete blinks and that this could account for some of the symptoms of dry eye reported by digital device users.

Incomplete blinking is important because it can result in increased tear film evaporation and shorter tear film break up times because of a reduced tear film thickness in the inferior cornea (McMonnies, 2007). The process of involuntary squinting can be helpful to the computer user because it can cause an improvement in acuity and help reduce glare caused by a glare source in the superior visual field (Sheedy, Truong, *et al.*, 2003). As such, if an individual demonstrates a reduced blink rate, or an increased number / percentage of incomplete blinks when using their digital device, this could be used as an objective means to diagnose DES. Blinking exercises have been shown to modify impaired blinking patterns and relieve the symptoms of dry eye (Kim *et al.*, 2020). Optometrists could advise their patients who experience dry eye while using digital devices to perform these exercises to help to reduce the severity of their symptoms. An example of such an exercise is as follows (Murakami *et al.*, 2014):

- Gently close the eyes for 2 seconds
- Open the eyes
- Gently close the eyes again for 2 seconds
- While keeping the eyes closed, squeeze the eyes for 2 seconds
- Open the eyes
- Repeat this cycle every 20 minutes during waking hours

Although this exercise was originally developed for the relief of evaporative dry eye disease, it may possibly be useful for those suffering from dry eye while using a digital device.

Accommodation and Convergence
There is a higher prevalence of accommodative and binocular vision disorders in symptomatic computer users than in the general population (Scheiman, 1996; Shrestha, 2020). To perform a near task comfortably, such as viewing a display screen, the pre-presbyopic user must be able to accommodate and maintain accommodation for the duration of the task (Wick and Hall, 1987). Lag of accommodation represents the deficit between accommodative demand and accommodative response (Gambra *et al.*, 2009). Wick and Morse (2002) demonstrated a lag of accommodation 0.33 D higher in 4 out of 5 participants when viewing a display screen compared to viewing the same material on paper and Collier *et al.* (2011) measured a greater average lag of accommodation in their study of 0.93 D during a 30 minute laptop based task in 20 adults. Hue *et al.* (2014) found that an increase in lag with an e-reader was associated with tired eyes and general eye discomfort. Tosha *et al.* (2009) reported that an increased lag of accommodation was associated with increased visual discomfort and resulted in an array of asthenopic symptoms such as blur, headaches and soreness. The accommodative lag experienced on a digital device could lead to eye strain for the worker which could be helped by prescribing spectacles to make up for this deficiency in required accommodation (Chase *et al.*, 2009). Spectacle lens manufactures now provide lens designs that incorporate an additional plus power to help pre-presbyopic computer users, these are commonly called ‘anti-fatigue’ lenses (Palavets and Rosenfield, 2019), however a 2022 study showed no improvement in DES (as measured by CVS-Q scores) when such lenses were used in pre-presbyopic device users (Del Mar Seguí-Crespo *et al.*, 2022).

Accommodative facility is a measure of the speed of the accommodative response (Pandian *et al.*, 2006). Step-change responses are often required when using a digital device to permit changes in fixation from the screen to other materials, such as notes, another digital device / screen or even into the distance, for example across an office. Sheedy and Parsons (1990) found poor accommodative facility in 31 of 153 (20 %) symptomatic computer workers, in fact it was the most common primary diagnostic cause of symptoms in 25 (16 %) of the workers (*primary* defined as being judged the most likely solution to the patient’s symptoms), with uncorrected presbyopia being the second. However, Rosenfield et al (2009) found that accommodative facility, when measured binocularly before and after a 25-minute computer task, unexpectedly improved after the task, such a finding could be linked to the short task duration used in this study (25 minutes) which is not reflective of the time often spent on screens by the average device user. Poor accommodative facility and the resulting focusing difficulties when using devices and switching fixation may contribute to DES.

Digital device users may put excessive demands on the eyes with respect to convergence often due to the close working distance used when viewing the device (Scot Best *et al.*, 1996; Jaschinski *et al.*, 1998; Boccardo, 2021). Watten *et al.* (1994) reported a significant decrease in vergence ability after 8 hours of computer work at a viewing distance of 40 cm. However, Yeow and Taylor (1989) found no significant change in the near point of convergence (NPC) after 4 hours of computer use in office workers. In 1993, Jaschinski-Kruza reported no change in fixation disparity after 30 minutes of computer use at viewing distances of 85, 47, 31 and 25 cm. Nyman *et al.* (1985) found no significant change in NPC or vergence of heterophorias after 5 hours of sustained computer work. In 1996 Cole *et al.* followed 692 computer users and 624 control office workers and monitored convergence and heterophoria, symptoms of DES were found in the computer users' group but there was no association with binocular function. Vergence response appears to be related to symptoms of discomfort while reading from a digital device. Collier and Rosenfield (2011) measured heterophorias and asked participants to rate the level of ocular discomfort (1 to 10 scale) before and after reading from a laptop computer for 30 minutes at a viewing distance of 50 cm. They reported greatest discomfort in participants who had less than 1 prism dioptre of esophoria or exophoria, thereby concluding that a smaller vergence response might reduce symptoms of DES. It should be noted that these studies are over 20 years old, and it is feasible that the results obtained with the latest design of screens and devices could well differ if these studies were repeated today.

Based on these findings, optometrists should perform an assessment of accommodation and binocular vision at the working distance of the device as part of their eye examination when presented with a symptomatic digital device user (Rosenfield, 2016).

Pupil Responses

Changes in pupil responses and characteristics can be an indicator of eye strain, with increases in pupil size being linked to visual fatigue (Chi and Lin, 1998), however, Gray *et al.* (2000) found a significant increase in pupil size after a 20 minute visual display task in non-symptomatic users. Saito *et al.* (1994) reported that after 4 hours of computer work, the pupillary light reflex was delayed or sluggish and the amplitude of the near reflex was decreased. Ukai *et al.* (1997) suggested that the visual fatigue reported by computer users could be associated with the rhythmic contraction of the pupil or hippus. Taptagaporn and Saito (1990) found that pupil sizes remained relatively unchanged when a user viewed a screen that had dark characters on a bright background (so called 'positive display') whereas the opposite display type of bright characters on a dark background (so called 'negative display') caused greater changes in pupil size. In addition, most of the computer users preferred the 'positive display' to the 'negative display' leading the authors to conclude that the former is more ergonomic and less likely to cause visual fatigue in users. It should be noted that this study was performed using CRT displays and results may be different when a more modern LCD screen is used. However, because it would be difficult for studies of pupil responses to digital device use to be assessed in standard optometric practice (due to time constraints and specialised equipment), these findings may be useful only as an objective assessment of DES when a symptomatic patient in a specialist clinic is examined.

1.4.3 Contributory Factors and Management of Digital Eye Strain

Several factors will lead to, or contribute to, the occurrence of DES in a typical device user. It is likely that a combination of these factors will lead to a greater level of symptoms in the user (Blehm *et al.*, 2005). Because many of these factors are ocular it is feasible that the sufferer will approach their optometrist for help in managing the condition.

The Ocular Surface

The TFOS DEWS II report defined the ocular surface as comprising the structures of the eye and adnexa, including the cornea, conjunctiva, eyelids, eyelashes, tear film, main and accessory lacrimal glands and the meibomian glands (Craig, Nichols, *et al.*, 2017). Ocular surface and tear film abnormalities, including reduced tear stability, alterations in tear volume and composition, increased oxidative stress, ocular surface inflammation and meibomian gland dysfunction have been found in computer / device users (Stapleton *et al.*, 2017; Choi *et al.*, 2018; Talens-Estarelles *et al.*, 2020). Accordingly, the TFOS DEWS II epidemiology report has listed digital device use as a consistent risk factor for dry eye disease (Stapleton *et al.*, 2017). Given this it is believed that individuals with pre-existing dry eye conditions are at an increased risk of suffering from digital device induced dryness and it is commonly found in device users who otherwise have healthy eyes (Uchino *et al.*, 2013; Mobeen *et al.*, 2016; Talens-Estarelles, García-Marqués, *et al.*, 2022). Digital device use can disrupt blink patterns, ocular surface homeostasis and tear film function in both children and adults (Moon *et al.*, 2014; M. Park *et al.*, 2014; Kim *et al.*, 2017; Choi *et al.*, 2018; Golebiowski *et al.*, 2020). Questionnaire-based studies have reported that the severity of dry eye is affected by the duration of the device use, with use of over 1 hour more likely to cause symptoms (Kumar *et al.*, 2014; Mobeen *et al.*, 2016). The use of air conditioning in office environments, discussed further below, will further increase symptoms for the user; the ocular surface, especially the cornea, is very sensitive to dry recycled air (which often contains contaminants such as paper dust) and as this air is circulated it will lead to increased drying of the ocular surface of the device user (Sotoyama *et al.*, 1995; Blehm *et al.*, 2005; Talens-Estarelles, García-Marqués, *et al.*, 2022).

Alterations in humidity or direct airflow exposure have been associated with dry eye symptoms, especially in indoor settings (Wolkoff and Kjærgaard, 2007; Koh *et al.*, 2012; Idarraga *et al.*, 2020; Talens-Estarelles *et al.*, 2021; Zayed *et al.*, 2021). Both low and high humidity have been associated with dry eye, likely due to low humidity causing tear evaporation and thinning of the tear film (Wolkoff and Kjærgaard, 2007; Wolkoff, 2017) and high humidity environments favouring the transmission and growth of microorganisms (Wolkoff and Kjærgaard, 2007; Gorski *et al.*, 2016). Optimal recommended humidity ranges from 40 % to 50 % (Wolkoff and Kjærgaard, 2007; Pulimeno *et al.*, 2020). Using a humidifier in office has been shown to modestly alleviate dry eye signs and symptoms in digital device users and may be useful in workplaces with low relative humidity (Hirayama *et al.*, 2013; Wang *et al.*, 2017). A study in New Zealand found that screen users, after completing a computer task for 1 hour, both with and without a humidifier, reported greater ocular comfort and an average increase of 4 seconds ($p<0.001$) in tear break up time (TBUT) when using a USB-powered desktop humidifier (Wang *et al.*, 2017). Therefore, a desktop humidifier may be beneficial in the reduction of dry eye amongst digital device users.

Generally a higher level of dry eye symptoms is found in females than in males (Stapleton *et al.*, 2017; Sullivan *et al.*, 2017). Two studies in the United States found a prevalence of 7.8 % in females (Schaumberg *et al.*, 2003) compared to 4.3 % in males (Schaumberg *et al.*, 2009). However a larger scale study in Japan, which sought to evaluated the association between daily screen use and dry eye in people aged 40 to 74 years, found a greater difference between the sexes (Mehra and Galor, 2020). The study reported a prevalence of 22 % of dry eye in males after 5 or more hours of screen use and of 36.5 % in females after 5 hours of screen use; the prevalence was less when screens were used for 1 hour, with a prevalence of 16.1 % in males and 26.5 % in females. Such differences between the sexes could be attributed to higher tear film evaporation among women who would therefore be more likely to experience dry eyes (Guillon and Maïssa, 2010).

The regular use of lubricating eye drops has been shown to reduce, but not eliminate, dry eye symptoms as well as some symptoms of tiredness and focusing difficulties (Blehm *et al.*, 2005; Wolffsohn *et al.*, 2023). The effects of decreased or incomplete blinking on dry eye must also be considered (as discussed previously). It may be useful to introduce blink training to computer users, where the user is prompted by their device to blink regularly using a message on screen or by an audible cue (Portello *et al.*, 2013). Scheduled regular breaks have also been found to be important in reducing DES and helping to increase overall work efficiency (McLean *et al.*, 2001; Fenety and Walker, 2002). Lubricating drops are especially important in older adults because of the link between dry eye and age as outlined in the TFOS DEWS II report (Craig, Nelson, *et al.*, 2017) with each decade of life being associated with a 24 % increase in the odds of developing dry eye disease (Wang *et al.*, 2020), yet little is known of the effects of device use and DES in this age cohort.

Nutrition

Nutrition can play a role in reducing symptoms of DES and research has shown that patients are open to, and happy to, to receive nutritional advice from their optometrist

(Downie *et al.*, 2017). For ocular surface dysfunction, enhanced anti-inflammatory benefits with omega-3 polyunsaturated fatty acids (PUFAs) has been shown to be beneficial in dry eye disease (Mulqueeny *et al.*, 2015; Thode and Latkany, 2015; Liu *et al.*, 2016; Chinnery *et al.*, 2017; Chi *et al.*, 2019; Giannaccare *et al.*, 2019; Pellegrini *et al.*, 2020). Omega-3 PUFAs also serve an important role in the prevention of chronic systemic conditions such as diabetes and cardiovascular disease (Wall *et al.*, 2010; Cicero *et al.*, 2012; Eckert *et al.*, 2013; Yessoufou *et al.*, 2015), in addition to having protective effects against cataracts (Iwig *et al.*, 2004; Jacques *et al.*, 2005; Lu *et al.*, 2005) and age related macular degeneration (Smith *et al.*, 2000; Seddon *et al.*, 2003; Robman *et al.*, 2007; Age-Related, 2013). In their 2015 study Bhargava *et al.* showed that short-term omega-3 fatty acid supplements were beneficial to symptomatic patients with DES and in 2016 further showed that omega-3 fatty acid supplements improved symptoms of DES and tear stability in young and middle age visual display terminal users. Flavonoids (found in citrus fruits, berries, apples and legumes) have also demonstrated anti-oxidative, anti-inflammatory and immunomodulating properties (Panche *et al.*, 2016). Intake of the flavonoid, anthocyanin (found in cranberries, black currants, red grapes and strawberries) has been shown to reduce symptoms of DES, such as tired eyes and eye fatigue (Ozawa *et al.*, 2015; Park *et al.*, 2016). Xanthophyll carotenoids lutein and zeaxanthin, as well as meso-zeaxanthin, play a fundamental role in maintaining retinal integrity in addition to promoting optimal central visual acuity (Bernstein *et al.*, 2016). Given their distribution in the central fovea, they comprise the macular pigment which preserves the local tissue by absorbing blue light and actively neutralizing free radicals to prevent oxidative damage (Junghans *et al.*, 2001; Krinsky and Johnson, 2005). Multiple studies have shown the therapeutic benefits of carotenoid supplements in conditions such as diabetic retinopathy, open angle glaucoma and especially age related macular degeneration (Gruszecki and Sielewiesiuk, 1990; Bone *et al.*, 1993, 2001, 2007, 2020; Koh *et al.*, 2004; Bernstein *et al.*, 2010, 2016; Akuffo *et al.*, 2014; Huang *et al.*, 2015; Lem *et al.*, 2021c, 2021b, 2021a). In 2020 Kan *et al.* found a significant improvement in symptoms of visual fatigue and dry eye in 360 adults who suffered from DES when they took a lutein supplement for 90 days and Kawabata *et al.* (2011) found a subjective improvement in symptoms of DES in 20 adults who took a supplement containing lutein, omega-3 fatty acids and anthocyanin for 4 weeks. As such there does appear to be increasing evidence that dietary supplements containing one or all of omega-3 fatty acids, flavonoids and carotenoids may be beneficial in reducing symptoms of DES.

Screen Positioning

The positioning of the display screen or digital device is an important factor when dealing with DES. Device users often adopt an unusual posture to allow them to see the screen or device clearly. As a result the user will often experience pain or discomfort in their back, shoulders, neck or wrists when using the device (Zayed *et al.*, 2021). Therefore, the position of the device, its height and distance, must be considered carefully when setting up a work station because improvements to it have been shown to reduce symptoms and improve performance (Liao and Drury, 2000). Three studies compared eye strain on screens at different viewing distances, 66 to 98 cm, 50 to 100 cm and 63 to 92 cm. In all studies, the longer viewing distance resulted in the lowest amount of eye strain (Jaschinski-Kruza, 1991; Jaschinski *et al.*, 1998, 1999) with a distance of between 88 cm and 100 cm producing lower levels of eye strain; this latter viewing distance is greater than the usually recommended minimum of 50.0 cm to 63.5 cm (German DIN 66234, 1981; Ankrum, 1996), and may not be practical in a typically designed workstation and nor for hand held devices where viewing distances are much shorter (Boccardo, 2021).

Screen height is also important. The screen should be placed 10 to 20 degrees below eye level (Allie *et al.*, 2005). If the screen is higher than this the user will often tilt their neck upwards resulting in muscle strain and discomfort (Sheedy, 1992; Allie *et al.*, 2005). Lowering the screen downwards allows the device user to look downwards thereby narrowing the palpebral aperture and reducing the area of the ocular surface exposed which will help reduce tear film evaporation (Bababekova *et al.*, 2011). Research has compared screen height, 5 degrees and 35 degrees below fixation, and showed that lower screens cause less eye strain than higher ones and that the user also prefers this lower screen position (Heuer, 1993).

Screen quality and refresh rate (defined as the frequency with which the image on an electronic display screen / monitor is refreshed and is usually expressed in hertz) have also been implicated in DES. Modern display screens have average refresh rates of 60 Hz but can be as high as 300 Hz (Haynes, 2022). If the refresh rate is too low the characters on the screen will appear to flicker and perceived flicker has been shown to cause fatigue and headache in the user (Costanza, 1994). Jaschinski *et al.* (1996) compared high refresh rates (300 Hz) with lower rates (50-90 Hz) and found that at the lower rate, accommodation was minimally weaker (0.06 D), the average interval between blinks was 15 % longer and the blink duration was 6 % shorter. Liquid crystal displays (LCD) are now the industry standard in monitor selection with the use of cathode ray tubes (CRT) displays becoming increasingly rare. LCD screens have extremely high refresh rates making them essentially flicker free which helps to increase visual comfort for the user. However, research has shown that prolonged use of even these screens can lead to symptoms of DES (Blehm *et al.*, 2005; Omran Al Dandan *et al.*, 2020) but this can be reduced, but not eliminated, by positioning the screen in a similar plane / angle and viewing distance that the user would normally adopt when reading printed text (Köpper *et al.*, 2016).

Blue Light

Modern digital devices, including computers, tablets, smart phones and e readers, emit ‘blue light’ also referred to as high energy visible light (Vision Council, 2016). Blue light is typically defined as visible wavelengths between 400 nm and 500 nm (Mainster and Sparrow, 2003; Algvere *et al.*, 2006; Tosini *et al.*, 2016). This part of the spectrum may be responsible for damage to photoreceptors in the retina (Margrain *et al.*, 2004) and may alter the body’s circadian rhythm (Tosini *et al.*, 2016). It has been reported that visible light-induced damage in photoreceptor-derived cells is wavelength dependent, with short wavelength light in the blue spectrum having a more severe toxic effect compared to either white or green light (Kuse *et al.*, 2014), animal studies have shown that retinal damage induced by LEDs is also wavelength dependent (Jaadane *et al.*, 2015). Although human exposure to short wavelength light generally is chronic and subthreshold rather than acute and suprathreshold, as was the case in these animal studies (Margrain *et al.*, 2004), the studies implicate short wavelength light as potentially pathologic; it may also be the case that chronic blue light exposure may exhibit itself as accelerated aging (Barja, 2002; Liang and Godley, 2003).

The impact of blue light on the eye has gained increased interest in the last several years given the increasing use of digital devices. However, even with long hours of use, the level of blue light exposure from digital devices is significantly less than the levels of blue light exposure from normal daylight and well below international safety limits (O'Hagan *et al.*, 2016). Despite this, excessive exposure to blue light has been suggested to cause DES and sleep disruption following night-time blue light exposure (Ayaki *et al.*, 2016; Heo *et al.*, 2017). However more recent studies have found no benefit to post-cataract patients receiving blue-light blocking intraocular lenses (IOL) in terms of sleep quality as compared to those receiving ultraviolet-light blocking IOLs (Adams *et al.*, 2022). Furthermore a 10 year study in Taiwan found no difference in the occurrence of AMD in patients receiving a blue-light blocking IOL to those patients receiving a non-blue-light blocking IOL (Lee *et al.*, 2022).

Several optical manufactures are now marketing spectacle lenses that include 'blue-blocking' (or blue-reducing) filters that reduce the transmission of UV light (200 to 400 nm), short wavelength light (380 to 440 nm) and blue light (440 to 500 nm) (Leung *et al.*, 2017; Palavets and Rosenfield, 2019). Claims have been made that these lenses potentially reduce eye strain (Ide *et al.*, 2015), improve quality of sleep (Ayaki *et al.*, 2016) and protect against retinal cell damage (Margrain *et al.*, 2004). However, there is limited evidence to suggest that DES results from exposure to blue light from digital devices (Downie, 2017; Lawrenson *et al.*, 2017). In 2014 the effect of low, medium and high density blue light filters in wrap around goggles was tested in two groups of 20 dry eye and 20 normal subjects (Cheng *et al.*, 2014). The results showed an improvement in DES symptoms in the dry eye group. However, the study did not use a control group so a placebo effect cannot be ruled out, in addition, the goggles may have helped to reduce tear evaporation in the dry eye group which could have helped reduced their symptoms.

In 2019 Palavets and Rosenfield examined the effect of a blue blocking filter on symptoms of DES during a sustained near task. The filter used blocked 99 % of wavelengths between 400 and 500 nm, while the control group used a neutral density filter. The results showed that the blue blocking filter was no better in reducing symptoms of DES than the neutral density filter a finding that was also found in a 2022 study by Adams *et al.* (2022).

The use of blue blocking lenses has attracted interest from the media in the UK. In 2015 the UK Advertising Standards Authority found an advertisement from an optical retailer promoting the use of blue blocking lenses constituted misleading advertising 'in the absence of adequate substantiation' and an investigation by the consumer protection programme 'Watchdog' on the BBC in 2016 expressed concerns about misleading advice in relation to the blue light emitted from digital devices and its effects on eye strain and visual fatigue. In view of these limited research findings and media controversies, there is a need for guidance on their use. The College of Optometrists (UK) has issued such guidance and has stated that:
"The best scientific evidence currently available does not support the use of blue-blocking lenses in the general population to improve visual performance, alleviate the symptoms of eye fatigue or visual discomfort, improve sleep quality or conserve macular health" (College of Optometrists, 2018). The College's position paper further states that if a practitioner is selling blue-blocking lenses then they should inform their patients that there is "*no strong evidence*" that that these lenses alleviate the symptoms of DES and that it is also "*unclear if the filtering of blue-light preserves macular health or alters the risks associated with the development or progression of AMD"*. As such the College of Optometrist's members should follow this guidance in practice and the College should ensure that the guidance is updated and amended when or if new evidence is reported.

Refractive Error

As discussed earlier correction of refractive error, especially astigmatism and presbyopia, is accepted as an important way of helping with symptoms of DES (Wiggins and Daum, 1991; Wiggins *et al.*, 1992; Venkateshvaran *et al.*, 2023). Uncorrected astigmatism may be a concern for presbyopic patients who choose to use ready-made reading glasses because these optical devices do not contain a correction for astigmatism (Rosenfield *et al.*, 2012). Contact lens wearers with small uncorrected astigmatism can also suffer because of a similar problem (Wiggins *et al.*, 1992). The variety of working distances that occur when using different digital devices can also cause problems for presbyopic individuals. Smart phones use small fonts because of their small screen size and are typically viewed at around 32 cm (Bababekova *et al.*, 2011; Long *et al.*, 2017), a minimum viewing distance of between 55 cm and 63.5 cm is recommended for a desktop computer (Ankrum,

1996) and 50 cm for e-readers (Shieh and Lee, 2007). Therefore, a single near addition may not be sufficient for the range of viewing distances involved. Presbyopes will often require multiple prescriptions / spectacles or a specialist occupational type lens that combines the intermediate prescription and near prescription. Such occupational lenses have been shown to reduce symptoms in presbyopic device users to a greater extent than workstation changes, 80.7 % reduction due to the occupational spectacles compared with 19.3% with the work station set up (Butzon *et al.*, 2002). Horgen *et al.* (2004) showed that some designs of specialist occupational lenses gave greater overall satisfaction than that achieved using single vision lenses.

1.5 Conclusion

The extensive use of digital devices for work, socialising and entertainment is now customary amongst people of all ages. The prevalence of DES is frequently reported to be around 50 % (Portello *et al.*, 2012; Tauste *et al.*, 2016), although since the COVID-19 pandemic and the increased use of digital devices, this rate may now be higher (Zayed *et al.*, 2021). This is an area that would benefit from further research because the increased use of these devices is likely to remain high even after the pandemic (Sultana *et al.*, 2021).

Given the ocular nature of many of the symptoms of DES, many sufferers will likely attend their optometrist for advice (even if this is not their primary reason for the visit) and as such, it is important that optometrists are well informed of the evidence regarding the condition. Optometrists will need ongoing education and training, especially as the research in this area develops, and there will be specific areas in which the profession will need further guidance and instruction. To facilitate this training, it is imperative that research is done to identify possible areas for the development of knowledge.

Prevention and modification of the way devices are used is the main strategy for the management of DES (Rosenfield, 2011). Those suffering from DES should have a full refractive correction for the appropriate working distances. The device user needs an ergonomically designed workplace / environment to limit symptoms. The use of handheld digital devices is likely to increase and these devices will require specific guidance because of to the difference in the modality of their use in compared to ‘traditional’ desktop or laptop computers (Bababekova *et al.*, 2011). Guidance on maintaining normal blinking patterns, taking regular breaks and use of ocular lubricants also needs to be provided and advice on nutrition should also be considered.

The use of instruments in the diagnosis of DES are useful although there is a shortage of validated questionnaires. Currently available questionnaires, such as the CVS-Q, are designed for working age adults and have predominantly been used in this context. Little has been done to assess these questionnaires’ suitability and repeatability in older adults and this is an area that would benefit from further research.

There is a shortage of data in Ireland and the UK about the prevalence of DES and how greatly DES impacts those affected is not well understood, i.e., is DES a minor inconvenience or a more significant concern?

In addition, little is known about how optometrists approach DES sufferers, how they amend their routine when they encounter a patient with signs and symptoms of DES and what advice / management they provide to these patients. There is also little information about DES and its effect on older age groups as previous research has typically focused on young and working age adults and children.

1.6 Rationale

This programme of research will seek to answer the questions posed above.

- It will investigate the attitudes of optometrists in the UK and Ireland to DES and how they manage it.

- It will determine the occurrence rate of DES in device users, both in working age and older adults and will investigate if the syndrome differs in these age groups.
- It will assess the reliability of an existing instrument, CVS-Q, used in diagnosing DES in older adults and will determine a minimum clinically important difference for this age group which could be useful in confirming if an intervention for DES is effective or not.

CHAPTER 2

ATTITUDES OF OPTOMETRISTS IN THE UK AND IRELAND TO DIGITAL EYE STRAIN AND APPROACHES TO ASSESSMENT AND MANAGEMENT

2.1 Introduction

Given the high prevalence of digital eye strain (DES), many optometrists will be examining patients with DES multiple times per day. Furthermore, affected patients may reasonably expect specialist advice on management from their optometrist given the ocular and visual nature of most DES symptoms. However, little is known about how optometrists perceive the growing problem of DES and their approaches to identifying and managing patients who may be affected (Sheppard and Wolffsohn, 2018). To date, no previous studies have assessed practitioners' knowledge and attitudes to DES, or whether current practice patterns are consistent with both the available research evidence in this field and the guidance, such as from the College of Optometrists (UK) on examining display screen equipment (DSE) / computer users (College of Optometrists, 2021) and use of blue filtering spectacle lenses (College of Optometrists, 2018). Hence, the present study sought to survey UK and Irish optometrists' knowledge, attitudes and clinical practices regarding DES.

2.2 Methods

The study received a favourable opinion from the Health and Life Sciences Research Ethics Committee at Aston University (#1652) and was conducted according to the tenets of the Declaration of Helsinki. A web-based survey of registered optometrists in the UK and Ireland was conducted following a pilot version to optimise the coverage and comprehension. Participation was voluntary, and before beginning the survey, respondents were required to indicate their consent after reading the participant information and transparency statement. The questionnaire was anonymous, although respondents had the option of providing their email address if they wished to be informed of the results of the study. No financial incentive was provided to respondents.

Sample and Materials

Qualified optometrists registered in the UK and Ireland were eligible to participate in the study. The number of optometrists in the UK and Ireland combined is approximately 17,800 based on *circa* 17,000 optometrists in the UK (General Optical Council, 2020) and *circa* 800 in Ireland (Ireland, 2018). Sample size calculation is important in all aspects of research as using an adequate sample size will help in the collection of high quality data which is more reliable and valid for the cohort being studied (Bartlett, 2001). An appropriate sample size renders the research more efficient, represents the population better and allows for confidence in conclusions drawn from the data (Faber and Fonseca, 2014; Andrade, 2020). For 95 % confidence and a ± 5 % margin of error in responses, a required sample size of 376 responses was determined for the survey (Qualtrics, 2020).

The questionnaire was designed to examine the attitude towards and understanding of DES by optometrists; how optometrists approach the examination of patients who may be affected by DES, and the opinions of optometrists towards various management options. Questions were worded to be culturally appropriate, succinct and accurate in their request for information from the participant. Following initial development of the questionnaire by academic optometrists with research interests in DES and the ocular surface / dry eye, a pilot online survey of eligible respondents was undertaken to obtain feedback on the relevance and ease of understanding of the items. Participants in the pilot were from various practice settings, e.g. independent practices, multiples etc.., were registered for different lengths of time and were from both the UK and Ireland. Minor changes to the survey items were made following feedback from the pilot; none of the 19 pilot responses were included in the final analysis.

The questionnaire was hosted by *Online Surveys* (https://www.onlinesurveys.ac.uk/), a General Data Protection Regulation (GDPR) compliant platform designed for academic research. The survey, consisted of 22 items in 4 key areas: respondent details (3 items); attitude and understanding of DES (6 items); examination of possible DES sufferers (7 items), and management of DES (7 items). A summary of the final questionnaire is shown in table 2.1 below. Following the section collecting data on participant demographics, fourteen of the remaining nineteen items gathered ordinal responses using 5-point scales allowing neutral responses. The Likert scale was used to measure agreement with attitude statements (e.g. *Digital Eye Strain is an important concern for optometrists*), a reported frequencies scale was used for behaviours (e.g. *How often do you ask patients about their computer or digital device use during routine case history?*), and a stated importance scale for the various management options (e.g. *How important do you think it is to advise on taking regular breaks and looking into the distance for digital eye strain?).* Three items in the attitude and understanding of DES section required free-text responses (*What do you understand by the term Digital Eye Strain? What percentage of patients attending your clinic do you believe are affected by Digital Eye Strain? What do you consider to be the typical symptoms of Digital Eye Strain?*). Respondents also had the opportunity to provide free-text responses to items linked to modification of the eye examination routine for patients who may be affected by DES; advice given regarding office environment and workstation set up; names of preferred (if any) topical lubricants, specialist spectacle lenses and blue-blocking lenses, and the final item of the survey asked for any other comments respondents wished to provide linked to DES and optometric management. Within the survey, if respondents reported that they 'never' asked patients about their use of digital devices, the subsequent four questions linked to case history were skipped. Similarly, if respondents stated that they 'never' modified their routine eye examination for patients who may be affected by DES, the associated question about clinical tests performed was skipped.

The survey was open between October 2020 and February 2021. All local or area optometric committees in the UK and the Association of Optometrists (Ireland) were contacted by email by the research team to request circulation of an invitation to their membership to participate in the research or promotion via their social media. Following a request to the College of Optometrists (UK) research team, a *Tweet* also promoted the survey to College followers.

Section	**Question numbers**	**Summarised questions**
About you	1-3	Main practice setting. Country of practice. Number of years since qualification.

Attitude towards and understanding of DES	4-9	Importance of DES to optometrists. Understanding of the term 'DES.' Proportion of patients believed to be affected by DES. Typical symptoms of DES. Level of agreement that DES can cause frequent and persistent symptoms. Confidence discussing DES symptoms.
Examination of those possibly affected by DES	10-16	Frequency of asking re: digital device usage in routine case history. Frequency of asking re: type of device(s) used. Frequency of asking re: time spent on device(s). Frequency of asking re: working distance of device(s). Frequency of asking re: symptoms of DES. Frequency of modifying eye examination for those possibly affected by DES. Clinical tests performed if examination modified.
Management of DES	16-23	Importance of regular breaks. Importance of topical lubricants. Importance of advising on environment and workstation set up. Importance of specialist spectacle lenses. Importance of 'blue-blocking' spectacle lenses. Any other comments re: optometric management of DES.

Table 2.1: Summary of 22-item digital eye strain questionnaire for optometrists in the UK and Ireland, hosted on *Online Surveys*.

Following closure of the survey, data were exported into Excel for initial analysis and cleaned to remove any inappropriate responses (e.g. incomplete). For items evaluating agreement with a statement, responses were grouped into 3 categories: *Agree* (Strongly Agree + Agree); *Neither Agree or Disagree* (No Opinion) and *Disagree* (Strongly Disagree + Disagree). Item 6 asked respondents to indicate numerically the percentage of patients attending their clinic who they believed were affected by DES; if respondents indicated a range of values, then the midpoint value was included in the analysis, whilst non-numeric responses were removed. The median and interquartile range were calculated. Spearman's *r* was used to examine the relationship between number of years since qualification and 1. Level of agreement with DES being an important concern for optometrists, and 2. Level of confidence in discussing symptoms and advising on management options. A p value of <0.05 was considered significant. For items involving free text responses, answers were coded and assigned to categories by a single investigator (the researcher) and were further validated by another investigator.

2.3 Results

Profile of Respondents

Four hundred and ten responses were received in total; 4 responses in which the country of registration (Ireland or UK) had not been stated were removed from the analysis. Approximately 2.3 % of registered optometrists in Ireland and the UK completed the survey and with 406 responses in the final analysis, the required sample size of 376 was surpassed. Three hundred and twenty-seven respondents (80.5 %) were based in the UK and 79 respondents (19.5 %) in Ireland. Table 2.2 illustrates the number of years registered and main practice setting of respondents; the most common main practice types were independent (46.6 %) and large multiple (33.7 %).

Years registered		**Main practice setting**	
	Percentage % (n)		**Percentage % (n)**
0-5 years	16.7 % (68)	Independent	46.6 % (189)
6-10 years	13.5 % (55)	Large multiple	33.7 % (137)
11-15 years	12.6 % (51)	Small multiple	6.7 % (27)
16-20 years	15.3 % (62)	Education/ academic	5.9 %(24)
21-25 years	13.1 % (53)	Public hospital	3.7 %(15)
≥26 years	28.8 % (117)	Private hospital	1.7 % (7)
		Other	1.7 % (7)

Table 2.2: Number of years registered as an optometrist and main practice setting of respondents. N = 406.

Attitude Towards and Understanding of Digital Eye Strain

The majority of respondents agreed that DES was an important concern for optometrists (88.9 %) and agreed that it may cause frequent and persistent symptoms for sufferers (91.9 %). Most respondents reported they felt confident in discussing possible symptoms of DES and management options with patients (91.4 %, table 2.3 below). There was no significant relationship between number of years qualified and agreement that DES was an important concern for optometrists (P = 0.400), and although respondents who had been qualified for longer periods were less likely to agree that they felt confident in discussing DES with patients, the relationship between the variables was weak (r_s = -0.198, r_s^2=0.04, P <0.001).

Figure 2.1 illustrates respondents' estimates of the proportion of patients attending their clinic whom they believe are affected by DES; 392 valid numerical responses were received for this item. Overall, the median response was 25 % (IQR = 10- 50 %), with 59.7 % of respondents estimating that 30 % or fewer of their patients are affected.

	Percentage % (n)		
	Agree	Disagree	Neither agree or disagree
DES is an important concern for optometrists	88.9 % (361)	6.2 % (25)	4.9 % (20)
DES may cause frequent and persistent symptoms for sufferers	91.9 % (373)	3.0 % (12)	5.2 % (21)
I feel confident discussing ocular symptoms associated with computer usage and advising on management options	91.4 % (371)	3.2 % (13)	5.4 % (22)

Table 2.3 Attitude towards DES. n = 406.

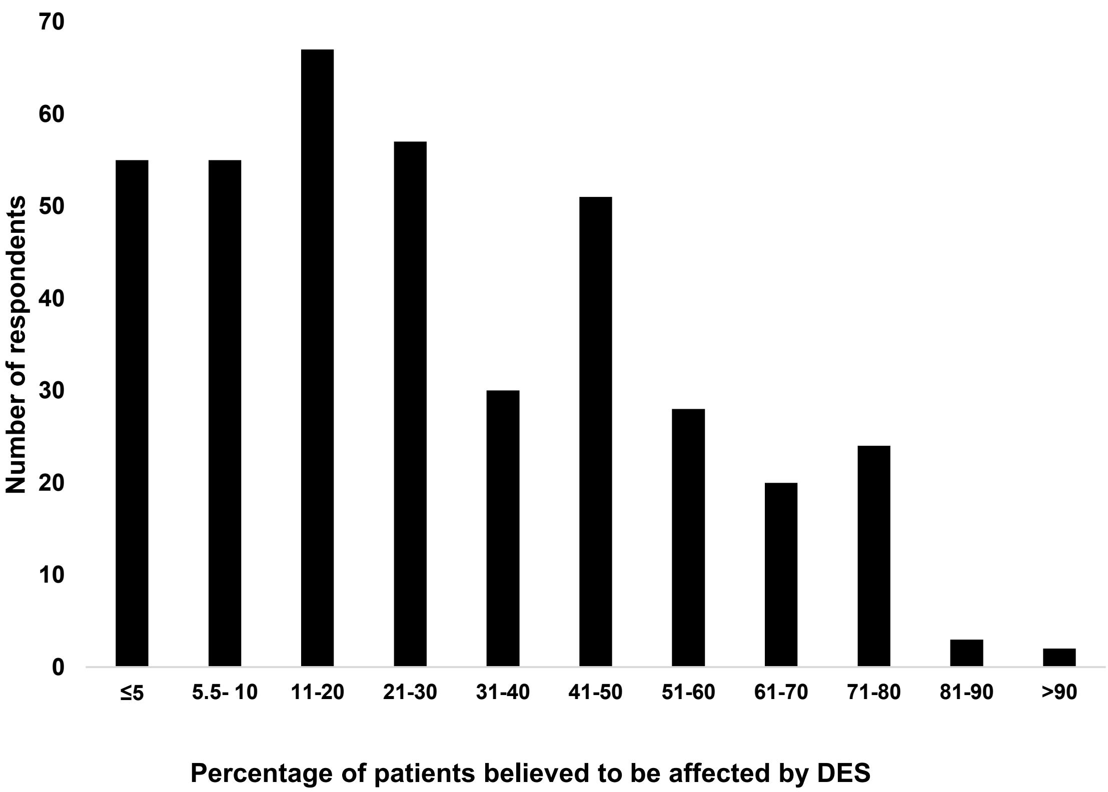

Figure 2.1: Practitioner perceptions of the proportion of patients attending their clinic who they believe are affected by DES. n = 392.

Regarding practitioner understanding of DES, of 388 valid written responses, 4 respondents (1.0 %) indicated they were unsure of the meaning of DES, whilst 3 (0.8 %) expressed scepticism / disbelief regarding the existence of DES. Of the remaining 381 responses, most (90.3 %) included reference to use of some form of screen-based technology leading to symptoms, and 65.6 % alluded to a variety of digital devices (rather than just conventional personal computers) being implicated. Of the symptoms that respondents associated with DES, 93.9 % referred to more than 1 key symptom, with the most frequently cited key symptoms being asthenopia or eye strain / fatigue (72.6 %); headache (64.7 %); dry or irritated eyes (56.0 %) and focussing difficulties or blurred vision (48.8 %). Table 2.4 details the symptoms respondents associated with DES.

Symptom	**Percentage % of respondents citing (n)**
Asthenopia or eye strain/ fatigue	72.6 % (284)
Headache	64.7 % (253)

Dry or irritated eyes	56.0 % (219)
Focussing issues or blurred vision	48.8 % (191)
Ocular soreness or redness	35.8 % (140)
Non-specific discomfort	6.6 % (26)
Photophobia or glare	6.1 % (24)
Binocular vision disturbance e.g. diplopia	3.6 % (14)
Musculoskeletal issues	3.1 % (12)
Insomnia	1.5 % (6)
Lid twitching	1.0 % (4)
Don't know	0.5 % (2)

Table 2.4: Key symptoms of DES cited by optometrist respondents (n=391).

Digital Eye Strain and the Eye Examination

Figure 2.2 illustrates the frequency of respondents asking various questions regarding digital device usage during routine case history taking. The majority of respondents (82.5 %) reported that they always (60.6 %) or frequently (21.9 %) asked patients regarding their use of digital devices, with only 5.1 % reporting they infrequently asked. No respondents reported that they never asked about device usage. Amongst respondents that asked about their patient's device usage, 78.8 % always or frequently asked about the type of device, whilst 75.1 % always / frequently asked about usage time per day and 9.1 % reported that they infrequently or never asked regarding each of these details. Information regarding working distance was ascertained by a similar proportion of respondents, with 74.1 % always or frequently asking and 9.3 % asking infrequently or never. Asking about the presence of symptoms with device usage received the fewest 'always' responses (32.0 %) of the case history questions, although 38.7 % also reported they frequently asked; 13.8 % infrequently or never asked regarding the presence of symptoms.

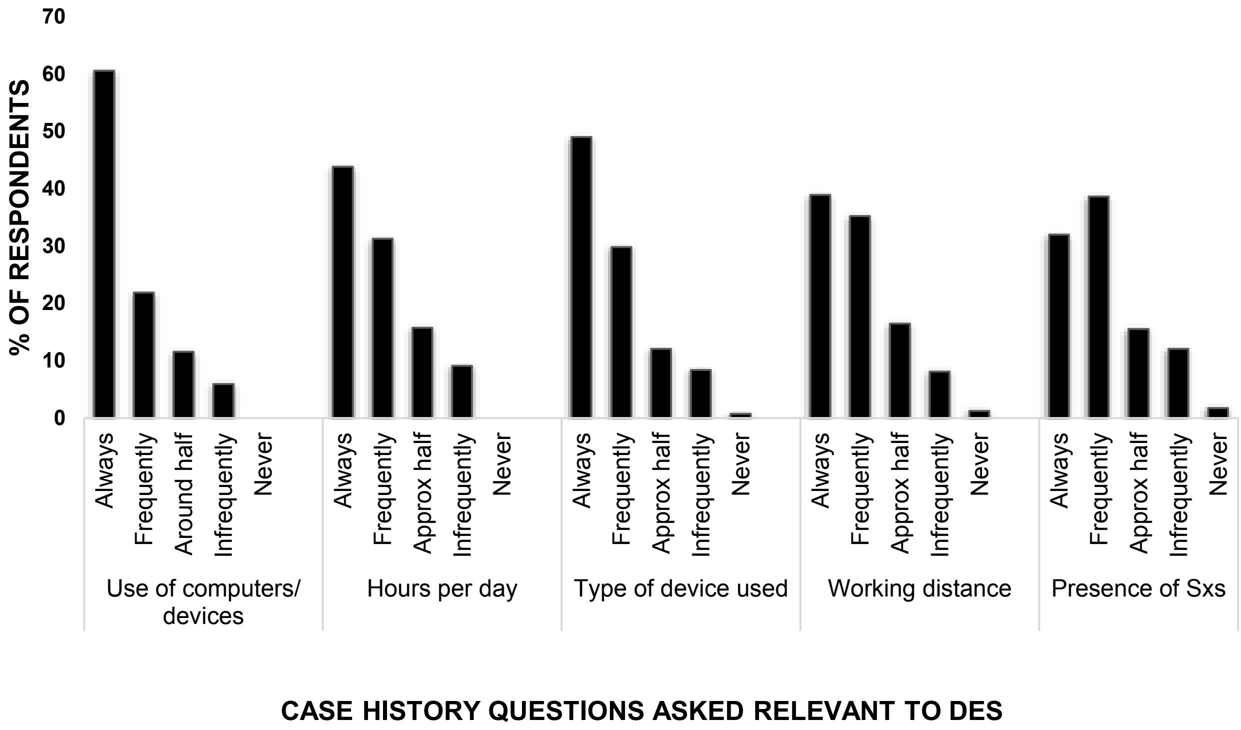

Figure 2.2: Frequency of asking questions regarding digital device usage during routine case history, n = 406 (Sxs = symptoms).

Regarding the clinical elements of the eye examination, 63.5 % of respondents reported that they always or frequently modified the eye examination for patients who may be affected by DES; 19.7 % did so infrequently or never. The modifications cited were assessment of acuity at specific distance of device (81.5 %); slit lamp biomicroscope examination of the ocular surface (79.1 %); other dry eye assessment techniques (67.7 %); near point of convergence (50.7 %); cover test at working distance of device (43.1 %); amplitude of accommodation (36.5 %); fixation disparity at working distance of device (25.1 %) and use of a dry eye questionnaire (7.9 %). Other modifications including dynamic retinoscopy, accommodative facility; macular pigment optical density, contrast sensitivity, AC/A ratio, range of clear vision and effect of a small amount of extra positive sphere were each cited by less than 1 % of respondents.

Attitude Towards Management Options

Figure 2.3 illustrates respondents' attitudes towards the importance of advising on the various management options for DES. Advising on regular breaks was considered to be extremely or very important by the majority (84.0 %) of respondents, with only 2.0 % reporting that this was not so / not at all important.

Advising on ocular lubricants and workstation set up was felt to be extremely or very important by 55.7 % and 69.2 % of respondents, respectively, with just 6.4 % and 3.9 % of respondents respectively, stating they felt advising on these was not so / not at all important. Two hundred and fifty-two respondents (62.1 %) provided details of advice given regarding environment / workstation set up. Of these responses, discussion of screen / desk / chair height was the most common recommendation, cited by 65.1 %, followed by consideration of working distance (49.6 %); environmental factors such as humidity and air conditioning (44.0 %); optimising lighting (40.1 %) and avoiding glare (25.4 %).

More mixed responses were received regarding the use of spectacle lenses for DES; for specialist spectacle lenses in general, 34.2 % felt these were extremely or very important, whilst a substantial minority (11.3 %) reported that they did not know how important it was to advise on these. Two hundred and three respondents provided information on the lens type(s) they recommended for patients with DES; amongst these responses 'office' type lenses were most commonly cited (54.7 %), followed by anti-reflective coated (26.1 %) and blue-filtering lenses (25.1 %). Accommodative support lenses and prescribing a refractive correction specific for the working distance were each mentioned by 17.7 %.

Few respondents felt that specific 'blue-blocking' lenses were extremely (4.4 %) or very important (10.8 %) in the management of DES; 27.3 % indicated they were somewhat important, while 37.2 % felt they were not so / not at all important and 20.2 % reported that they did not know. One hundred and forty-one respondents (34.7 %) indicated that they advised on the use of these, with Essilor (29.1 %), own-brand (27.0 %), Hoya (14.9 %) and Zeiss (12.8 %) variants being most commonly cited.

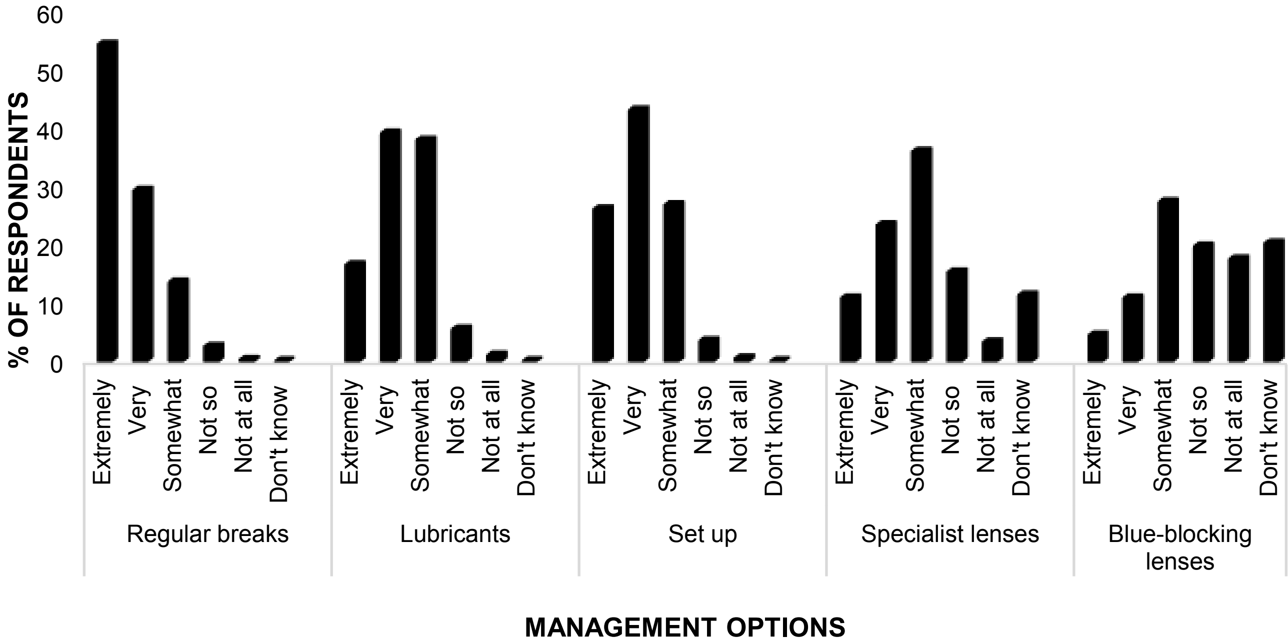

Figure 2.3: Respondents' perceptions of the importance of advising patients on various management options for DES, n = 406.

2.4 Discussion

This cross-sectional study of the attitudes, knowledge and practice patterns of optometrists in the UK and Ireland included a range of respondents, with a broad range of clinical experience and practice settings. The results of the survey highlight that optometrists in the UK and Ireland consider DES to be a significant issue for professionals, and a complaint that can cause frequent and persistent symptoms in those affected. A high level of confidence in discussing DES with patients and advising on available management options was identified. Together, these findings indicate that patients presenting to their optometrist with DES can expect to receive advice on symptoms and how to manage them.

Respondents' estimates of the proportion of patients in clinic affected by DES (median 25 %; IQR 10- 50 %) were generally lower than the prevalence's of the syndrome reported in relatively recent studies. Amongst office workers, DES prevalence has been reported as 53 % in Spanish civil servants using a validated questionnaire (del Mar Seguí *et al.*, 2015), and in New York City-based workers, approximately 40 % experienced tired eyes 'at least half of the time' (Portello *et al.*, 2012). A large-scale US-based survey of the general population (rather than computer workers specifically), found an overall self-reported prevalence of 65 % (Vision Council, 2016), and a recent study based in Saudi Arabia reported a 78 % prevalence of DES during COVID-19 restrictions (Alabdulkader, 2021). Gauging DES prevalence remains a challenge, with a range of diagnostic criteria used in previous studies (Sheppard and Wolffsohn, 2018), although the estimates provided by respondents in the present study do appear to be low. The low estimates could be reflective of the practice types of many respondents and an assumption that older individuals, who often comprise a large part of the patient base for community optical practices, are less likely to experience DES. There is a paucity of published evidence regarding the prevalence and impact of DES amongst older individuals, although it is known that amongst older age groups, engagement with digital devices and internet use has increased substantially in recent years (Chang *et al.*, 2015; Hunsaker and Hargittai, 2018), and the positive correlation between DES and dry eye symptoms (Portello *et al.*, 2012) suggests that a significant proportion are indeed likely to be affected.

The role of a range of digital devices was highlighted in the majority (65.6 %) of responses to the question '*What do you understand by the term Digital Eye Strain?'* Many studies have reported on ocular and visual symptoms arising from extended use of tablets, smartphones and mobile reading devices (Moon *et al.*, 2016; Kim *et al.*, 2017; Long *et al.*, 2017; Maducdoc *et al.*, 2017; Choi *et al.*, 2018). Whilst the aetiology of associated symptoms may be different compared to conventional computers (due to size, positioning and viewing angle) (Jaiswal *et al.*, 2019), it is accepted that use of these types of device can lead to DES. Consequently, the term 'Digital Eye Strain' has been advocated rather than 'Computer Vision Syndrome' (Rosenfield, 2016; Sheppard and Wolffsohn, 2018). The potential for multiple symptoms to be experienced due to DES was recognised by the majority of respondents (93.9 %), and the symptoms most frequently stated (eye fatigue and asthenopia, headache, dry eyes and focusing issues) were in alignment with commonly reported symptoms from previous studies (Portello *et al.*, 2012; del Mar Seguí *et al.*, 2015; Alabdulkader, 2021; Zayed *et al.*, 2021). Only a small proportion of respondents (3.1 %) cited musculo-skeletal symptoms such as neck and shoulder pain. Musculo-skeletal impacts have been included as part of the syndrome by numerous authors and organisations such as the American Optometric Association

(2017), and may be largely attributable to improper posture and / or device positioning (Sheedy and Parsons, 1990), although there are ophthalmic prescribing implications, particularly for presbyopic patients, in ensuring that prescriptions are appropriate for the required task distance and gaze angle (Rosenfield, 2016).

Regarding routine case history taking, the majority of respondents (82.5 %) reported that they always or frequently asked about digital device usage. Importantly, information about type of device (78.8 %), usage time (75.1 %) and working distance (74.1 %) was usually gathered by respondents. Each of these factors can influence the likelihood of symptoms and approaches to management. Gaze angle (and therefore palpebral aperture size and tear film distribution) will vary with different types of device, which in turn can impact upon symptoms. However, understanding of the interrelationship between device position / gaze angle and symptoms is limited by some ambiguity in previous studies as to whether angles represent eye rotation only or include neck flexion (Köpper *et al.*, 2016; Jaiswal *et al.*, 2019). Text size on some devices may be a problem, particularly with smartphones, where the visual acuity demand can be approximately 6/6 (Bababekova *et al.*, 2011). Given that a two-times acuity reserve (i.e. threshold acuity of 6/3 for a 6/6 demand level) is needed for comfortable prolonged reading from a digital device in younger age groups, and a higher reserve being likely for older patients or those with visual deficits (Kochurova *et al.*, 2015), small text size can be a significant contributor to DES symptoms. Information about both the type of device and working distance / position are useful in understanding the ergonomics of use and in the provision of appropriate advice for the patient (Coles-Brennan *et al.*, 2019), as highlighted in the College of Optometrists' guidance on examining patients who work with display screen equipment (College of Optometrists, 2021). It has been reported in a multitude of previous studies that the severity of DES symptoms increases with longer durations of use, and contact lens wearers may be particularly susceptible to symptoms following extended periods of use (Tauste *et al.*, 2016). Notably, the presence of symptoms with device usage was asked least frequently by respondents, with 29.3 % reporting that they asked around half the time or less, suggesting that many affected patients may not be receiving appropriate advice on management/ avoidance of symptoms.

The most commonly cited modifications of the eye examination for patients who may be experiencing DES were assessment of acuity at the working distance of the device(s) and slit lamp biomicroscope examination of the ocular surface. Appropriate correction of refractive error is important for digital device users, with uncorrected (simulated) astigmatism of as little as 0.50 - 1.00 DC having been shown to have a detrimental effect on subjective comfort with computer use (Wiggins and Daum, 1991), an effect which may be a particular problem amongst contact lens wearers with residual astigmatism (Wiggins *et al.*, 1992) or presbyopic users of ‘ready readers’ (Sheppard and Wolffsohn, 2018). Furthermore, any near add must be appropriate for the individual’s habitual tasks, recognising that multitasking with digital (and non-digital) tasks involving a range of viewing distances and gaze angles is common (Vision Council, 2016; Alabdulkader, 2021). Recent research indicating that the typical viewing distance for presbyopic smartphone users is 39.0 cm, whereas *minimum* distances of 50.0 - 63.5 cm have been recommended for desktop screens (German DIN 66234, 1981; Ankrum, 1996). The majority of respondents indicated they would assess the ocular surface or evaluate other indicators of dry eye, and many reported using accommodation and binocular vision tests in DES, highlighting that factors leading to both internal and external symptoms are being investigated by those who modify their routine in patients experiencing DES. However, with 36.5 % of respondents adapting the eye examination around half the time or even less frequently, factors contributing to the development of DES may not be explored in a significant proportion of patients.

In line with research demonstrating the beneficial effects of regular breaks on subjective comfort and working efficiency (McLean *et al.*, 2001; Galinsky *et al.*, 2007), and recommendations from organisations such as the College of Optometrists (College of Optometrists, 2020), the vast majority of respondents felt advising on breaks was important in the management of DES. Environmental factors and workstation set up were also perceived as important areas for advice. Ergonomic and environmental considerations for comfortable computer use include lighting and glare, screen and hardware positions, workstation furniture and temperature / air quality, and are covered by the Health and Safety Executive (HSE) guidance (Health and Safety Executive, 2021).

The use of specialist spectacle lenses in DES management was an area of less confidence amongst respondents, with 11.3 % reporting they did not know how important it was to advise on these and just 34.2 % feeling that they were extremely or very important. With a range of specialist lens types now available for both pre-presbyopic and presbyopic heavy users of digital devices and office workers, this could represent an area where more professional education would be of value. Apprehension regarding the value of blue-filtering lenses in DES was apparent, with just 15.2 % of respondents indicating that advising on these was extremely / very important, and 57 % reporting that these were not of value, or they did not know, although 34.7 % reported that they advised on particular blue filtering lens types. Similar scepticism from the profession regarding blue-filtering spectacle lenses was reported by Singh *et al.* (2019) following a survey of Australian optometrists, where the majority of respondents (89.2 %) felt that the quality of evidence to support the use of the lenses in digital eye strain was low or moderate, and only 3.8 % felt that there was high quality evidence in this area. Despite concerns regarding available evidence, three quarters of Australian optometrists reported that they recommended these in practice, with the most common reasons being device usage and suspected DES. In both studies, an appreciation of the lack of good quality evidence in this field is apparent (in line with the College if Optometrists' position statement on blue-blocking spectacle lenses (College of Optometrists, 2018)), although they were still recommended by many respondents which may be reflective of commercial pressures within optometry, or the belief of an associated placebo effect (Singh *et al.*, 2019).

Similar to previous surveys of the profession, a limitation of the present study is that optometrists motivated by personal interest in the topic may be more likely to respond than others (i.e. it is a self-selected sample) (Dabasia *et al.*, 2014), leading to a possible overestimation of confidence/ skills in this area of practice compared to the profession as a whole. Some optometrists surveyed may be involved in schemes / contracts with companies to provide for VDU / DES screening already and as such are more likely to make alterations to their eye examination than those that are not, which could affect the results obtained in the survey. The survey did take place during the COVID-19 pandemic which could have influenced the type of patients been seen by the participants and therefore influenced the results obtained. The 406 respondents represents around 2.3 % of optometrists registered in the UK and Ireland, with the response profile of UK respondents aligning reasonably closely to that of optometrists in the 2015 Optical Workforce Survey (College of Optometrists, 2015), where most respondents worked primarily in independent/ small group practice (52.7 %) or for a national company (32.7 %). In the present study, UK respondents were mainly from independent/ small group practice (52.7 %) or large multiples (36.4 %). Amongst responses from Ireland (19.5 %), a smaller proportion of respondents worked mainly in large multiples (24.1 %) compared to the UK, but more were from the private hospital sector (7.6 % vs 0.3 %).

It has been reported previously that practice patterns determined from survey-based research may not be reflective of true practice, with respondents tending to report higher standards of practice than may actually apply (Theodossiades *et al.*, 2012). It is feasible, therefore, that the results linked to case history questioning and modification of the eye examination may overestimate the frequency of enquiring regarding DES and undertaking investigations linked to the syndrome in patients who may be affected. Analysis of case records or use of clinical vignettes (Shah *et al.*, 2010) could be used in future research to better understand practice in this area.

2.5 Conclusion

The present study provides a valuable insight into the attitudes and practice patterns of optometrists in the UK and Ireland regarding the growing issue of digital eye strain. Given that optometrists consider DES to be both a significant problem for affected individuals and an important concern for optometrists, and most respondents reported they felt confident discussing DES with patients, the findings indicate that patients experiencing the syndrome can expect to receive useful clinical input from their optometrist. Overall, estimates of the proportion of patients affected by DES were significantly lower than reported prevalence's in the scientific literature, and whilst the majority of respondents indicated they asked patients about their device usage in routine case history taking, more routine questioning specifically linked to symptoms could help to identify a greater number of affected individuals. Respondents felt advising on frequent breaks, ocular lubricants and workstation / device set up were the most important management considerations, with more mixed views on specialist spectacle lenses for DES, particularly 'blue filtering' designs, although a significant proportion of respondents did indicate that they recommended these. Spectacle lens prescribing in DES may represent an area where further professional education would be of value.

Supporting publication: Moore, P.A., Wolffsohn, J.S. and Sheppard, A.L. (2021) ‘Attitudes of optometrists in the UK and Ireland to Digital Eye Strain and approaches to assessment and management’, *Ophthalmic and Physiological Optics*, 41(6), pp. 1165–1175.

CHAPTER 3
DIGITAL EYE STRAIN AND ITS IMPACT ON WORKING ADULTS IN THE UK AND IRELAND

3.1 Introduction

The use of varied digital devices has become ubiquitous amongst all age groups in recent years. A range of studies (Portello *et al.*, 2012; Gowrisankaran and Sheedy, 2015; Sheppard and Wolffsohn, 2018) have shown a high incidence of DES (e.g., up to 50 % or more), however few studies have examined the impact of DES on those affected and the ameliorative steps taken to reduce symptoms. In addition, while a link between DES and dry eye symptoms has been shown (Portello *et al.*, 2013; Rosenfield, 2016), few studies have attempted to measure dry eye prevalence using a validated instrument in those affected by DES and determine if there is a relationship between age, gender and hours of use.

Since the onset of the global COVID-19 pandemic, studies have shown that the prevalence of this condition has increased, this would not be surprising given the extensive use of digital devices by people working from home (where workstations designed for comfortable computer use may not be available) and for carrying out personal tasks, such as home shopping for food and other essential items (Pišot *et al.*, 2020; Vargo *et al.*, 2020; Sultana *et al.*, 2021).

There is a paucity of UK and Ireland data for the occurrence of DES, as discussed in chapter 2, a study of optometrists in this region (Moore *et al.*, 2021) highlighted that most practitioners (88.9 %) felt DES was an important concern and reported high levels of confidence in discussing DES and management options with patients (91.4 %). Practitioner estimates of the prevalence of DES (median 25 %, IQR 10- 50 %) were lower than most previously published reports. Studies have been done elsewhere, Portello *et al.* (2012) researched DES in New York (USA) and found 40 % of subjects reported their eyes being tired at least half the time while 32 % reported dry eye and 31 % reported eye discomfort, symptoms also varied with gender (being greater in females) and with ethnicity (being greater in Hispanics). In their Malaysian study, Reddy *et al.* (2013) found 89.9 % of university students had symptoms of DES with headache and eye strain being the most disturbing symptoms

(19.7 % and 16.4 % respectively), they also reported that students who used devices for more than 2 hours per day and students who wore spectacles experienced significantly more symptoms of DES. A study by Tesfa *et al.* (2019) in Ethiopia found 75.6 % of university secretaries experienced DES, participants who used devices for ≥6 hours per day were three times more likely to have DES than those who used their devices for <6 hours per day. In their Indian study, Ahuja *et al.* (2021) reported 62.4 % of computer users reported symptoms of DES, they also reported high levels of DES in spectacle wearers (78.1 %) and higher levels in males than females. Zayed *et al.* (2021) in an Egypt based study found a DES prevalence of 82.41 % among information technology workers in Tanta University. The study found that female gender, age ≥35 years, daily computer use of ≥6 hours and wearing spectacles were significant predictors of DES. As can be seen from these worldwide studies, DES prevalence rates can differ significantly as can the associated risk factors and symptoms. It is possible that DES prevalence, like dry eye, will differ between ethnic groups and between males and females (Wang, Muntz, *et al.*, 2021). At the time of writing, no similar study has been carried out in the UK or Ireland to determine if these populations will have similar or different findings to those carried out elsewhere in the world.

The aim of this study is to determine the prevalence of DES amongst adults who work with computers / digital devices in the UK and Ireland, the impact of their symptoms and ameliorative approaches taken by those affected.

3.2 Methods

The study received a favourable opinion from the Health and Life Sciences Research Ethics Committee at Aston University (#1769) and was conducted according to the tenets of the Declaration of Helsinki. A web-based survey of computer / digital device users in Ireland and the UK was conducted, following a pilot version to optimise the coverage and comprehension. Participation was voluntary, and before beginning the survey, respondents were required to indicate their consent after reading the participant information and transparency statement. The questionnaire was anonymous, although respondents had the option of providing their email address if they wished to be informed of the results of the study and / or enter a draw for one of five £50 vouchers for respondents who completed the survey in full.

Sample and Materials

Adults in Ireland and the UK who used a digital device for at least 1 hour per day for work purposes were eligible to participate. The questionnaire was designed to determine the prevalence of digital eye strain in computer / digital device users in Ireland and the UK along with their daily digital device usage, musculoskeletal and ocular symptoms, how they manage their symptoms and eye care history. Sample size calculation is important in all aspects of research as using an adequate sample size will help in the collection of high quality data which is more reliable and valid for the cohort being studied (Bartlett *et al.*, 2001). An appropriate sample size renders the research more efficient, represents the population better and allows for confidence in conclusions drawn from the data (Faber and Fonseca, 2014; Andrade, 2020). With an estimated working age population of 34.75 million (32.5 million in UK and 2.25 million in Ireland) (Statistica.com, 2022b, 2022c) across the two countries, the required sample size for a 95 % confidence interval and a ± 5 % margin of error would be 385 responses (Qualtrics, 2020).

The questionnaire was hosted by *Online Surveys* (https://www.onlinesurveys.ac.uk/), a General Data Protection Regulation (GDPR) compliant platform designed for academic research. The survey included items in 5 key areas (a summary of the questionnaire is shown in table 3.1 below). Following three initial items on respondent demographics (age, gender and ethnic group), the second part of the survey collected information regarding the respondent's use of digital devices, the types of devices used and duration of use. Respondents were asked if their use of digital devices had changed since the COVID-19 pandemic. It asked about symptoms of DES they may or may not experience and how they rank their symptom severity.

The next section of the survey included the 5 items from the validated Dry Eye Questionnaire (DEQ-5) (Chalmers *et al.*, 2010). Based on a typical day in the last month, the participant is required to report how often their eyes felt discomfort or dryness and the intensity of the feeling (0-5 scale) within 2 hours of going to bed. The fifth item links to eyes looking or feeling excessively watery. Possible scores range from 0 to 22; for screening purposes, it has been proposed that dry eye should be considered for scores > 6, scores >12 indicate severe dry eye symptoms and possible Sjogren's syndrome (Chalmers *et al.*, 2010). The findings in the TFOS DEWS II report indicate dry eye can only be diagnosed when there are both symptoms and objective signs (Craig, Nelson, *et al.*, 2017; Craig, Nichols, *et al.*, 2017), so while a positive score for dry eye on the DEQ-5 cannot alone be used to diagnose dry eye, the DEQ-5 has been shown to be comparable to the Ocular Surface Disease Index (OSDI) in discriminating symptoms of dry eye and can be considered a valid means for assessing dry eye symptoms in both clinical and epidemiological studies (Akowuah *et al.*, 2021).

Respondents also completed all items from the previously discussed validated Rasch-analysed Computer Vision Syndrome Questionnaire (CVS-Q) designed to measure visual symptoms related to computer use in the workplace (del Mar Seguí *et al.*, 2015). Respondents were further asked to indicate if they considered themselves to be affected by DES.

The final section of the survey questioned the device user about their eye care, such as time since last eye examination, use of visual correction while using digital devices and expectations of their eye examination for helping with DES.
Following initial development of the questionnaire by academic optometrists with research interests in DES and the ocular surface / dry eye, a pilot online survey of eligible respondents was undertaken to obtain feedback on the relevance and ease of understanding the survey. Participants in the pilot worked in various office settings, were gender and age balanced and, in so far as was possible, were from various ethnic groups. One change was made to the survey following this feedback, the participant information sheet (PIS) was shortened, however a hyperlink was available which the participant could click if they wished to get further information on the survey. None of the 23 pilot responses were included in the final analysis.

The survey was open for 15 weeks between October 2021 and January 2022. A request was made to Technological University Dublin (Ireland) and Aston University (UK) to distribute the survey to its workforce, 3500 (TU Dublin, 2022) and 1165 (Aston University, 2022) respectively. Smaller companies (local to the researcher's optometric practice) were also emailed to seek permission to distribute the survey. A significant response was achieved which allowed the researchers to exceed the minimum number of responses outlined above.

Following closure of the survey, data was exported into an Excel spreadsheet for analysis and cleaned. The survey was structured so that incomplete responses were not recorded. For the item involving free-text responses answers were coded and assigned to categories by a single investigator before being reviewed by a second investigator. Statistical analysis of the data using the Kolmogorov-Smirnov test (*K-S*) showed the data in this study was not normally distributed ($P<0.001$) and as such non-parametric tests, such as Spearman's rank-order correlation coefficient and Mann-Whitney U test, were used to analyse the data.

Section	**Item numbers**	**Summarised questions**
About you	1-3	Age Gender Ethnic group
Use of digital devices	4-7	Daily use of digital devices Working from home patterns Hours per day using devices Changes to level of device usage since the pandemic
Symptoms of DES, DEQ-5, CVS-Q, methods to relieve DES and self-reported DES	8-14a	Eye discomfort on a typical day and intensity. DEQ-5 Frequency of DES over the last month and intensity CVS-Q Methods to relieve DES symptoms Self-reported DES
Eye care and vision correction	14b-16	Time since last eye examination Expectations for DES management during the eye examination

		Vision correction used when using digital devices

Table 3.1: Summary of the 41-item questionnaire for adult digital device users in Ireland and the UK.

3.3 Results

Profile of the respondents

Four hundred and fifteen responses were received in total; four responses were removed from the analysis as the respondents stated that did not use computers or digital devices frequently, another ten responses were removed as their responses were highly inconsistent across different sections of the survey. A total of 401 responses were included in the final analysis which exceeded the required sample size of 385. Of the respondents 255 were female (63.6 %), 140 were male (34.9 %), 2 (0.5%) were non-binary, 3 (0.7 %) preferred not to say and 1 (0.2 %) chose to self-describe.

A breakdown of respondents ages is shown in table 3.2 below. Based on age, 33.9 % were pre-presbyopic (18-34 years), 19.2 % were incipient presbyopes (35-44 years) and 55.7 % were presbyopic (45 years and over) (Laughton *et al.*, 2018).

Age Band (years)	n (%)
18-24	27 (6.7)
25-29	28 (7)
30-34	46 (11.5)
35-39	35 (8.7)
40-44	42 (10.5)
45-49	64 (16)
50-54	68 (17)
55-59	44 (11)
60-64	36 (9)
65-69	7 (1.7)
70 and over	4 (1)

Table 3.2: Age bands of respondents (n=401)

With respect to their ethnic group, 361 (90 %) identified as white, 23 (5.75 %) as Asian, 7 (1.75 %) as mixed race, 4 (1 %) as black, 1 (0.25 %) as Arab, 2 (0.5 %) as other, 2 (0.5 %) preferred not to say and 1 (0.25 %) chose to self-describe.

Respondents place of work

Ninety (22.4 %) did not work regularly from home, 76 (19 %) stated they worked up to 15 hours per week at home, 104 (25.9 %) worked between 16 and 30 hours per week at home and 131 (32.7 %) worked for more than 30 hours per week at home.

Daily device type and usage

The device types that respondents said they used the most were smart phones followed by laptop computer, desktop computer, tablet and electronic ‘e’ reader.

A breakdown of device type and hours used is shown in table 3.3 below.

Daily duration (hours)			**Device type used n (%)**		
	Desktop	Laptop	Tablet	Smartphone	E reader
0	184 (45.9)	77 (19.2)	282(70.3)	18 (4.5)	348(86.8)
0.5	12 (3)	16 (4)	30 (7.5)	35 (8.7)	21 (5.2)
1	20 (5)	29 (7.2)	43 (10.7)	94 (23.4)	22 (5.5)
2	22 (5.5)	24 (6)	29 (7.2)	121 (30.2)	7 (1.7)
3	17 (4.2)	20 (5)	9 (2.2)	70 (17.4)	0 (0)
4	17 (4.2)	33 (8.2)	6 (1.5)	29 (7.2)	2 (0.5)
5	24 (6)	27 (6.7)	0 (0)	10 (2.5)	0 (0)
6	26 (6.5)	44 (11)	1 (0.2)	10 (2.5)	0 (0)
7	31 (7.7)	33 (8.2)	1 (0.2)	4 (1)	0 (0)
8 hours or more	48 (12)	98 (24.4)	0 (0)	10(2.5)	1 (0.2)

Table 3.3: Respondents digital device usage- type and daily duration (respondents could select multiple devices if applicable).

Of the 401 responses, 318 (79.8 %) indicated their usage had increased since the start of the pandemic, 81 (20.2 %) said it had remained the same and only 2 (0.2 %)

said it had decreased. Two hundred and sixty-one respondents (65.1 %) used digital devices for over 8 hours per day and 31 (7.7 %) reported using devices for ≥16 hours per day. The median number of hours for which devices were used was 9 (IQR 8-11). Spearman's rank-order correlation coefficient showed a weak negative relationship between age and hours per day of device use and age (r_s=-0.165, r_s^2=0.02722, P=0.001).

DEQ-5

The median DEQ-5 score was 8 (IQR 5-11), with a range of 0 to 21; 61.8 % of participants returned a score >6, 66.4 % of females had a score >6 and 52.1 % of males had a score >6. The age band with the greatest number of results >6 was 60-64 years, with 72.2 % of this band having a DEQ-5 result >6, the age band with the lowest occurrence was the 70 years and above, with 50.0 % of this band having a DEQ-5 result >6. Spearman's rank-order correlation coefficient showed no significant relationship between DEQ-5 and age (r_s=-0.00884, r_s^2=0.00007, P=0.860), however hours per day of device use and DEQ-5 did show a weak positive relationship (r_s=0.107, r_s^2=0.01145, P=0.0324).

Females had a median DEQ-5 score of 9 (IQR 6-11), males had a median DEQ-5 score of 7 (IQR 4-10). A Mann-Whitney U test showed that the median DEQ-5 score was significantly higher in females than males (U=14340.5; P=0.003). Of respondents, 65.1 % said they experienced eye discomfort sometimes or frequently on a typical day, 6 % of respondents said it never occurred.

Regarding eye dryness, 51.2 % of respondents reported it occurring sometimes or frequently on a typical day in the last month, with only 19.0 % saying it never occurred. Thirty four percent of respondents said that their eyes looked or felt excessively watery sometimes or frequently on a typical day during the last month with 30.9 % saying they never did. Figure 3.1 below shows the breakdown of symptom prevalence reported by respondents when answering the DEQ-5 questionnaire.

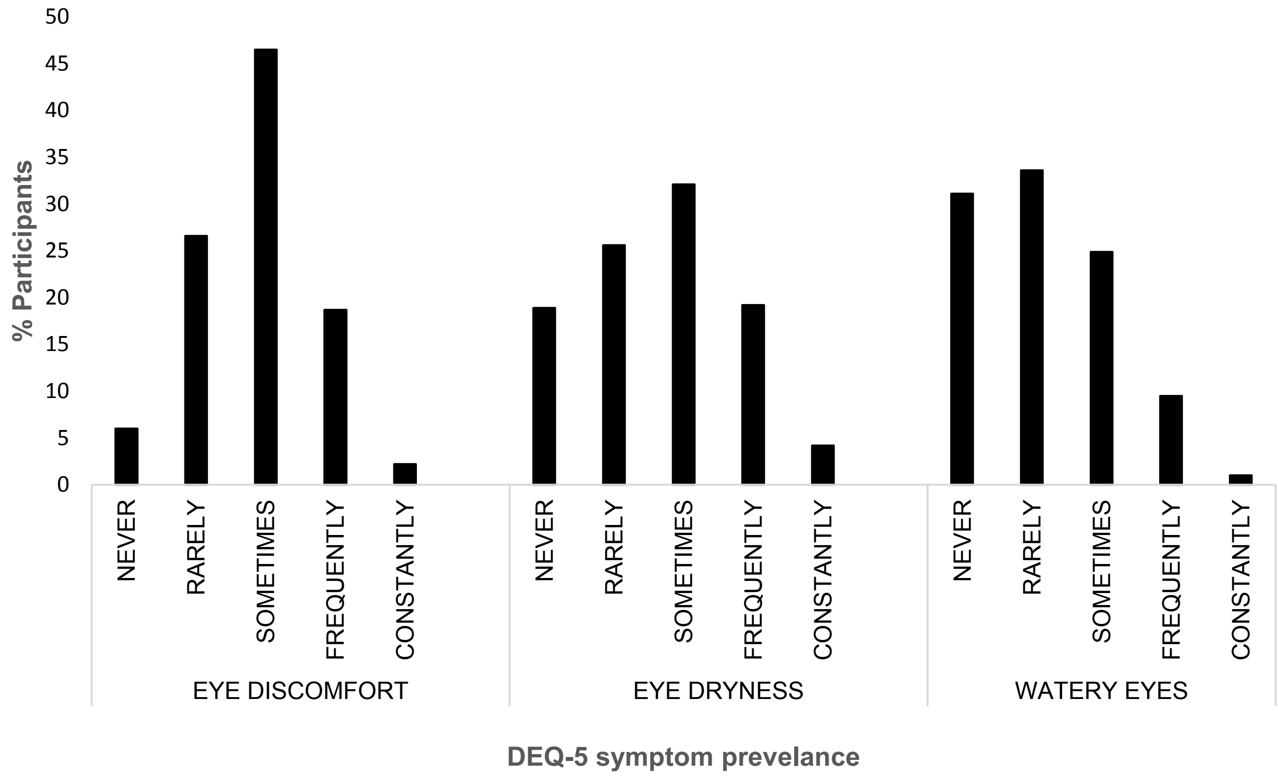

Figure 3.1: Occurrence of symptoms as reported on the DEQ-5 questionnaire on a typical day during the last month (n=401).

Of the 311 participants who said they worked from home (either fully or partially), 61.7 % had a DEQ-5 score >6 and of the participants over the age of 40, 61.5 % had a score >6.

Computer vision syndrome questionnaire (CVS-Q)

Two hundred and fifty-one (62.6 %) respondents returned a score ≥6 for the CVS-Q, the median score being 7 (IQR 4-10), with a range of 0 to 25, 70.7 % of females had a score ≥6 and 47.14 % of males had a score ≥6.

The age band with the highest percentage of results ≥6 was 50-54 years, with 77.92 % of this band having a CVS-Q ≥ 6, the age band with the lowest percentage was the 65-69 years, with 28.6 % of this band having a CVS-Q ≥6. Spearman's rank-order correlation coefficient showed no significant relationship between CVS-Q and age (r_s=-0.00769, r_s^2=0.00005, P=0.878), however hours per day of device use and CVS-Q did show a weak positive relationship (r_s=0.155, r_s^2=0.024, P=0.00183). Figure 3.2 below shows the full breakdown by age band.

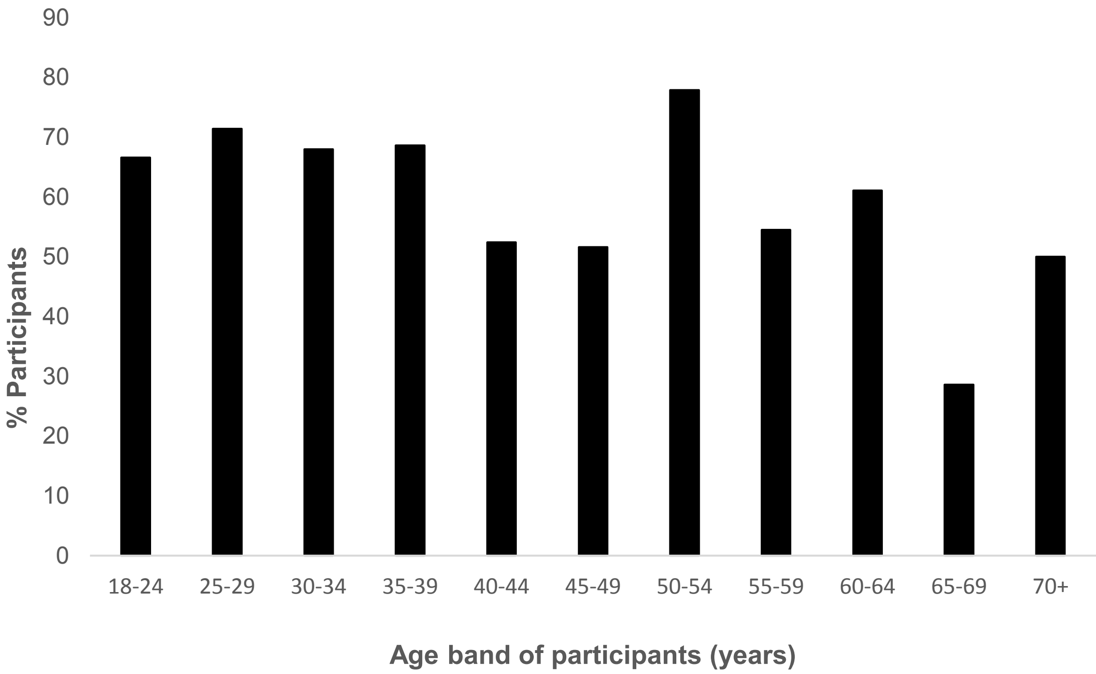

Figure 3.2: Percentage of participants by age band (years) with a CVS-Q ≥6

Females had a median CVS-Q score of 8 (IQR 5-11), males had a median CVS-Q score of 5 (IQR 2-9). A Mann-Whitney U test showed that the median CVS-Q score was significantly higher in females than males (U=12182.6; P<0.001).

The symptoms most commonly selected on the CVS-Q (as either 'occasionally' or 'often / always') were 'dryness' (n=265, 66.3 %), 'headache' (n=250, 62.3 %) and 'itching' (n=244, 60.8 %). The three least commonly selected symptoms were 'double vision' (n=57, 14.2 %), 'coloured halos around objects' (n=92, 22.9 %) and 'burning' (n=126, 31.4 %). A full breakdown of the frequency of symptom selected is shown in figure 3.3 below.

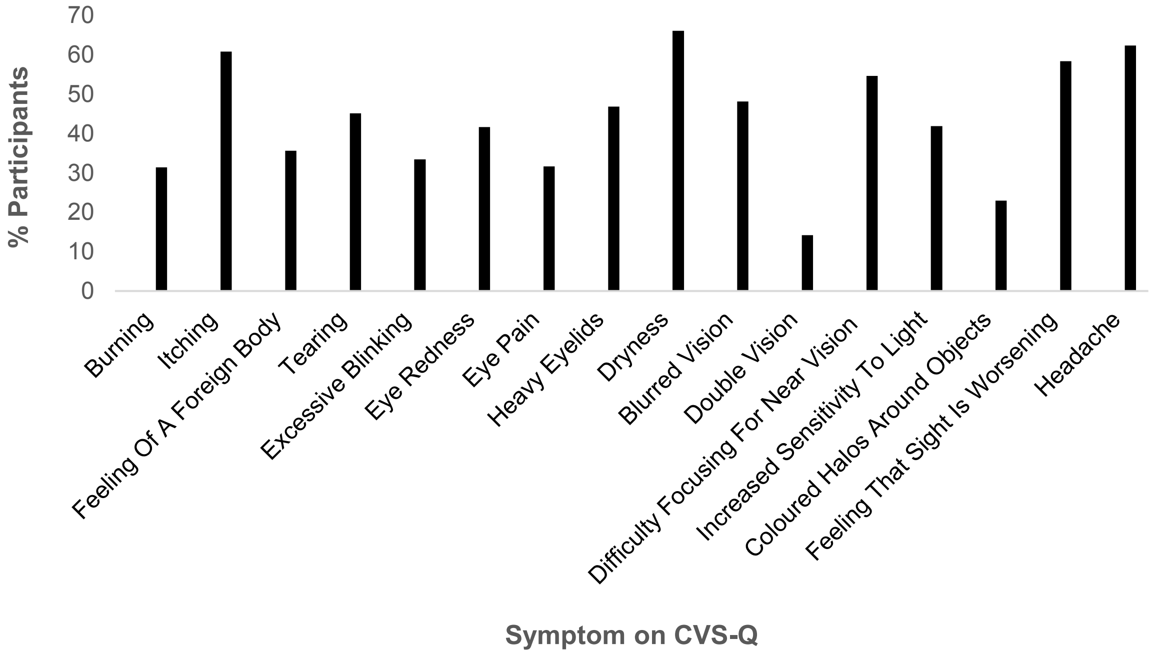

Figure 3.3: Percentage of participants selecting each symptom type on CVS-Q (n=401)

Of the 311 respondents who worked from home, 64.6 % had a CVS-Q score ≥6. When considering participants >40 years (n=265), 60 % had a CVS-Q score of ≥6. Of those who reported musculoskeletal symptoms (n=378), 64 % had a score ≥6 and of those who reported ocular symptoms (n=359), 68.5 % had a score ≥6.

When responses between the DEQ-5 and the CVS-Q questionnaires are analysed, the results are highly positively correlated with Spearman's rank-order correlation coefficient r_s=0.60, r_s^2= 0.36, P <0.00001 (figure 3.4 below).

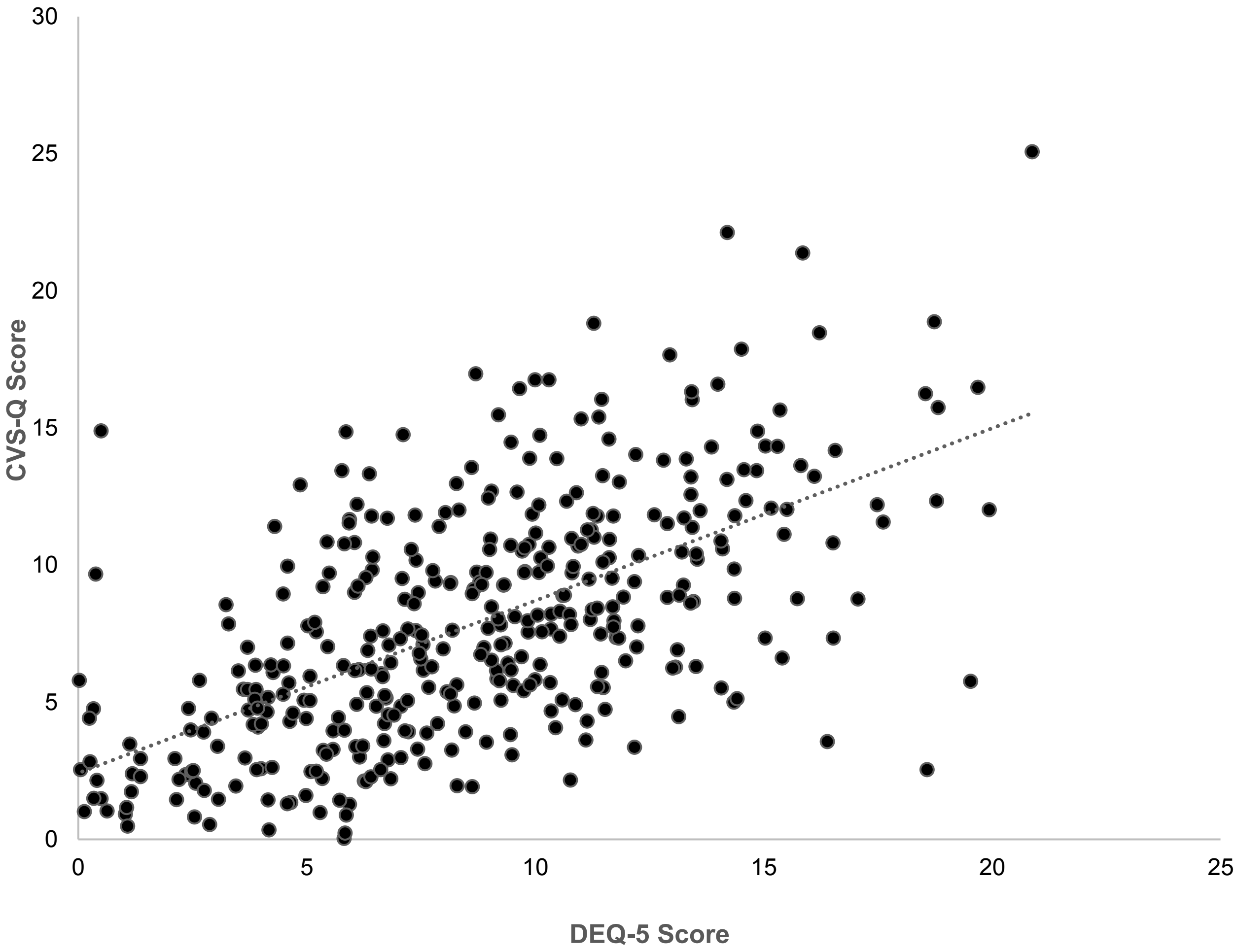

Figure 3.4: Correlation between participants DEQ-5 and CVS-Q scores, high positive correlation is shown with Spearman's correlation r_s=0.60, r_s^2= 0.36, *P* <0.00001. Data have been jittered to improve visibility of overlapping data points.

Musculoskeletal symptoms

378 (94.3 %) respondents reported symptoms such as neck, shoulder or back pain when using digital devices during the last month, with 50.1 % saying they occurred regularly (twice a week or more) or very frequently (most days), 30.7 % reported such symptoms occurring occasionally (approximately once a week).

Of the 378 who reported musculoskeletal symptoms, 64.4 % had a DEQ-5 score >6 and 64 % had a CVS-Q score ≥6. Of the respondents who did not regularly work from home 33.33 % reported having muscular symptoms 'regularly' or 'very frequently' whereas 55.32 % of those who worked a minimum of 16 hours per week from home reported having muscular symptoms 'regularly' or 'very frequently'.

Ocular symptoms

359 (89.5 %) respondents reported ocular symptoms (such as dryness / discomfort / visual problems / strain / headache) with 34.4 % saying they occurred regularly (twice a week or more) or very frequently (most days).

Of those 42 respondents who reported never having symptoms, the highest percentage was in the 45-49 years age group, 23.8 %, with the lowest being in the 25-29, 65-69 and 70+ age groups, all being 2.3 %. Of the respondents who did not regularly work from home, 24.44 % reported having ocular symptoms ‘regularly’ or ‘very frequently’ whereas, 39.15 % of those who worked a minimum of 16 hours per week from home reported having ocular symptoms ‘regularly’ or ‘very frequently’.

When the participants who reported ocular symptoms (n=359) were asked to rate how much their symptoms ‘bothered’ them (on a scale of 1 to 10, 1 being least bothersome and 10 being most bothersome) 4.7 % rated them as being barely noticeable (‘bother’ score of 1), 42.6 % rated them as being minor (‘bother’ score of 2 or 3), 44.6 % rated them as being frequent / annoying but not problematic or affecting work (‘bother’ score of 4, 5 or 6), while 8.1 % said they were severe enough to affect their work (‘bother’ score of 7, 8, 9, or 10). Of this symptomatic group, 69 % had a DEQ-5 >6 and 68.5 % had a CVS-Q ≥6. The median of the ‘bother score’ was 3 (IQR 2-4). When responses between ‘bother score’ and DEQ-5 are analysed the results are highly positively correlated with Spearman’s rank-order correlation coefficient r_s=0.63, r_s^2= 0.3969, *P* <0.00001 in females and r_s=0.71, r_s^2= 0.5041, *P* <0.00001 in males. Similarly, when responses between ‘bother score’ and CVS-Q are analysed the results are highly positively correlated with Spearman’s rank-order correlation coefficient r_s=0.51, r_s^2= 0.2601, *P* <0.00001 in females and r_s=0.69, r_s^2= 0.4761, *P* <0.00001 in males. When responses between ‘bother score’ and muscular symptoms are analysed the results are positively correlated with Spearman’s rank-order correlation coefficient r_s=0.41, r_s^2= 0.1681, *P* <0.00001 in females and r_s=0.43, r_s^2= 0.1849, *P* <0.00001 in males. Figure 3.5 below shows a breakdown of the ‘bother score’ results reported by percentage of participants, figure 3.6 shows a scatter plot of ‘bother score’ and CVS-Q.

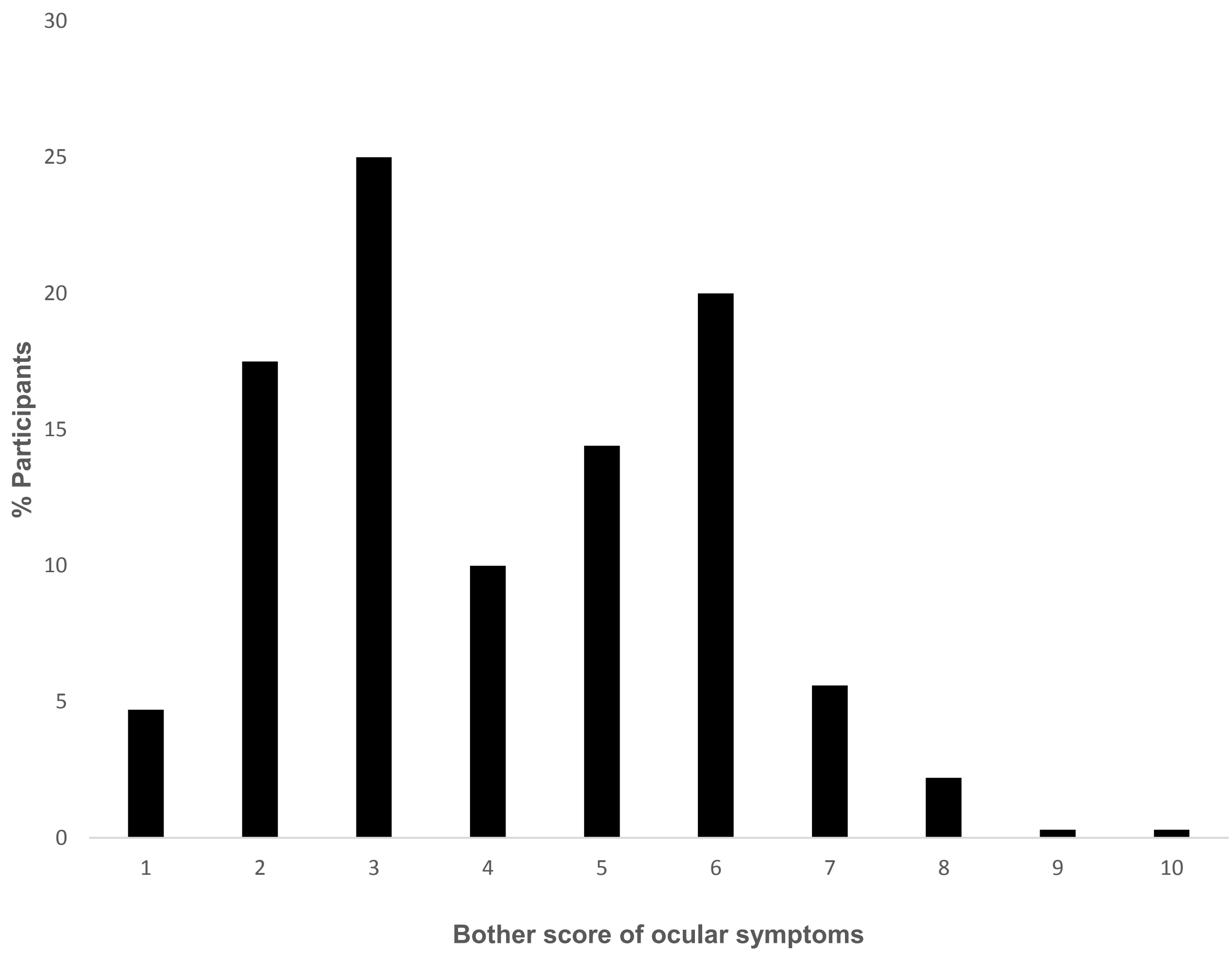

Figure 3.5: Scale of 1 to 10 on how bothersome symptoms were when reported by participants (%) n=359

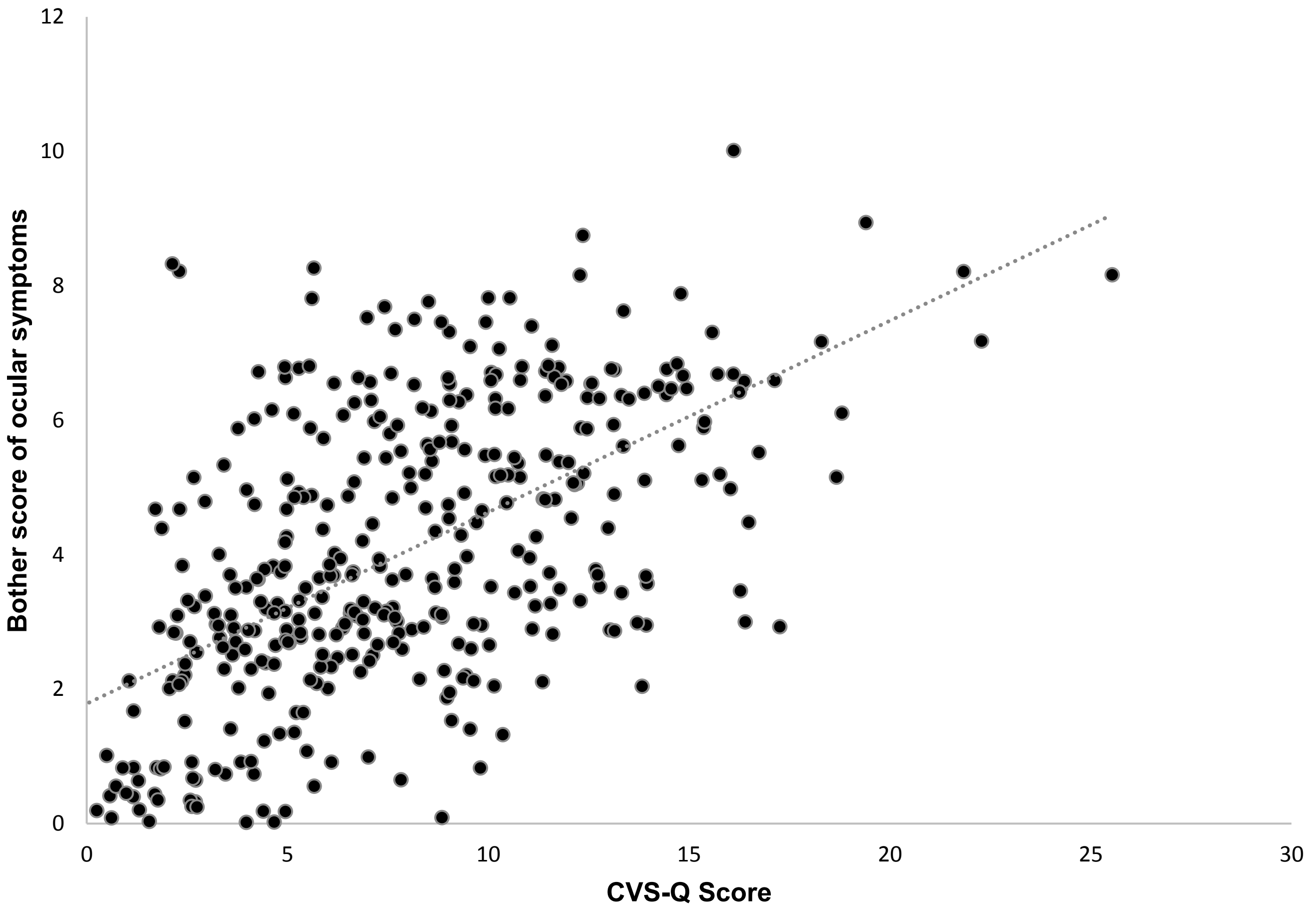

Figure 3.6: Scatter plot of bother score of ocular symptoms and CVS-Q score of participants (n=401) showing positive correlation and trendline. Data have been jittered to improve visibility of overlapping data points.

Methods used to relieve symptoms

Of the respondents 7.2 % had not tried anything to relieve their symptoms when using digital devices. Taking regular breaks from the device was the most selected method to reduce symptoms (62.3 % participants), followed by looking away from the screen frequently (49.4 %) and then by adjusting room lighting / window coverings (40.9 %). Some 30.2 % used lubricating drops and 37.7 % used their regular spectacles while 11 % mentioned using specialised 'computer spectacles'. Adjusting the screen settings, such as brightness / colour was mentioned by 34.7 % of the participants, and 13.2 % adjusted their room environment, such as temperature / humidity to help relieve their symptoms. Taking pain medication was mentioned by 15.7 % as being necessary to help cope with their symptoms.

Self-diagnosed digital eye strain

Two hundred and forty-eight or 61.8 % of respondents selected ‘yes’ when asked if they considered themselves to be affected by DES, with 38.2 % selecting ‘no’. Comparing ‘self-diagnosed’ DES to the results obtained using the CVS-Q showed agreement in 75 % of participants, agreement between ‘self-diagnosed’ DES and having dry eye (using the DEQ-5) was found in 71.1 %. Females were more likely to diagnose themselves with DES than males, 65.5 % as opposed to 55 %. The age-bands 50-54 years and 35-39 years self-diagnosed DES the most, 69.1 % and 65.7 % respectively, the 65-69 age band was the least likely to self-diagnose DES (42.8 %). Of the 248 participants who said they thought they were suffering from DES, 81.8 % had earlier indicated that their usage of digital devices had increased since the onset of the COVID-19 pandemic. Additionally, 26.9 % had indicated that they worked from home for between 16 and 30 hours per week and 34.1 % indicated they worked from home for more than 30 hours per week. When CVS-Q results for values ≥6 are compared to ‘self-diagnosed’ DES, the results are positively correlated with Spearman’s rank-order correlation coefficient r_s=0.46, r_s^2= 0.2116, P <0.00001.

Eyecare

One hundred and eighty-four or 45.9 % of respondents reported having had an eye examination less than 1 year ago, 23.7 % had one between 1 and 2 years ago, 15.7 % had one between 2 and 3 years ago and 6.2 % had one between 3 and 4 years ago. Of those who ‘self-diagnosed’ having DES, 70 % had an eye examination in the last 2 years. Three hundred and four participants or 75.8 % said they would expect their optometrist to provide advice on managing DES during a routine eye examination with 11.2 % saying they would not. The remaining participants, 13 %, did not know or were not sure. Regarding what type of visual correction used (if any) while operating their digital device, 44.6 % used single vision spectacles, 23.4 % used multifocal spectacles and 3.7 % used ‘ready made reading’ spectacles. Contact lenses were used by 6.2 % and a further 6.2 % of participants alternated between contact lenses and spectacles. Specialised ‘computer’ spectacles were used by 11 % of the respondents. No correction was used by 27.2 % of respondents.

Of those who ‘self-diagnosed’ DES, 44.3 % used single vision spectacles, 26.6 % used multifocal spectacles and 4.4 % used ‘ready-made reading’ spectacles. Of those wearing contact lenses, 56 % 'self-reported' DES, while 60.5 % of those using no visual correction 'self-reported' DES.

3.4 Discussion

This cross-sectional survey of digital eye strain (DES) in computer / digital device users in Ireland and the UK and their associated symptoms was the first of its kind and included respondents with a broad range of device usage, various DES signs and symptoms and eye care history. It appears to be, at the time of writing, the first published data on the occurrence of DES (which was already known to be high even before the pandemic) in Ireland and the UK, it examined the impact of those affected by DES and the link between DES and dry eye.

Of the 401 valid respondents, 54.5 % were aged between 40 and 59 years, 33.9 % were aged between 18 and 39 years and the remainder, 11.7 % were aged over 60 years. This represents a good variation of age and allowed the prevalence of DES to be assessed and compared across these different age cohorts. Analysis showed that there was no significant correlation between age and DES (as determined by the CVS-Q) or between age and dry eye symptoms (as determined by the DEQ-5). Other studies have shown a significant link between age and DES and dry eye and DES, such as Uchino *et al.* (2013) and others have not, such as Portello *et al.* (2012). The former study was carried out in Osaka (Japan) and the latter in New York (USA). The participants of the Portello *et al.* (2012) study were 50.3 % white and 11.7 % Asian whereas the ethnic breakdown for Uchino *et al.* (2013) was not disclosed however the participants were described as 'Japanese office workers' so it could be presumed that they were predominantly Asian. In this study the participants were 90 % white and 5.75 % Asian, this could account for a similar finding with respect to age and DES and dry eye symptoms and DES as found by Portello *et al.* (2012) and could suggest that device users who are white are less likely to experience DES than other ethnic groups. Given that Asian ethnicity is a predisposing risk factor for dry eyes (Wang and Craig, 2019) and the established link between dry eye and DES (Stapleton *et al.*, 2017; Choi *et al.*, 2018; Talens-Estarelles *et al.*, 2020), this finding is therefore not a surprising one.

A negative correlation between age and hours per day of device use was shown in this study and a positive correlation was shown between hours per day of device use and DES (as measured by the CVS-Q). This would agree with findings in other studies (Portello *et al.*, 2012; Uchino *et al.*, 2013; Tesfa *et al.*, 2019; Zayed *et al.*, 2021) were DES was shown to be associated with long hours of device use. Significantly these other studies were conducted in various parts of the world with a variety of ethnic groups and as such this would suggest that ethnicity may not be a factor when considering hours of use and DES.

The gender breakdown of the respondents in this study was 65.6 % female and 34.9 % male. Participation rates of females in online surveys has been shown to be higher than males (Smith, 2008) so this is not a surprising outcome. Given that the female percentage in the workplace in the UK is 47.6 % and 45.8 % in Ireland (WorldBank, 2020) it would appear that the female responses are in excess of that in the general workplace population (WorldBank, 2020). Many studies in DES (both recent and older) have found higher rates in females and this study would agree with this finding (Schaumberg *et al.*, 2003; Portello *et al.*, 2012; Rosenfield, 2016; Alabdulkader, 2021; Chawla *et al.*, 2021).

Based on a CVS-Q score ≥6 the occurrence of DES in this UK and Ireland population was high, 62.6 %, with females having a significantly higher median score than males. Other studies, such as that by Portello *et al.* (2012), have shown a lesser level of DES of around 50 %, where as other research has suggested it may be even higher than that found in this study, at between 64 % and 90 % (Hayes *et al.*, 2007; Yan *et al.*, 2008). Another survey of computer users showed that 'visual complaints' were reported by 75 % of computer users who work 6–9 hours per day in front of their screens (Mutti and Zadnik, 1996). A further survey of 419 computer users in India reported that 46.3 % of the users experienced two or more symptoms of DES either during or after computer work (Bhanderi *et al.*, 2008). Additionally, DES was also reported in over 50 % of call centre computer workers in Sao Paulo, Brazil (Sa *et al.*, 2012). Research since the COVID-19 pandemic has shown varying prevalence's of DES, such as 82.41 % by Zayed *et al.* (2021) and 62.4 % by Ahuja *et al.* (2021). These studies have used various criteria for the diagnoses of DES which could explain their differing results. It would be beneficial to the research in this area if all studies used a recognised and validated instrument for the diagnoses of DES, such as the validated CVS-Q, to make their results comparable. Working from home also appeared to be linked to higher CVS-Q scores with 64.6 % of those working from home having a score ≥6, this is not a surprising finding as it may not be possible to set up an ergonomically designed workstation at home as easily as in an office environment.

Another key finding of the study is that most (75.8 %) of the respondents said they would expect their optometrist to provide advice on managing DES, this combined with the increasing use of digital devices, will result in more users attending their optometrist looking for help in dealing with this condition. This finding, combined with the research by Moore *et al.* (2021) that 88.9 % of optometrists agree that DES is an important concern for them in practice and that 91.4 % say they feel confident in dealing with it, shows that the optometry profession is in a good position to deal with and manage this condition in their patients. Moore *et al.* (2021) further found that 91.9 % of optometrists agreed that DES can cause frequent and persistent symptoms for sufferers, therefore the device user should be confident that their concerns about DES will be taken seriously and dealt with correctly.

Analysis of the type of device(s) used by the participants found that most used a smart phone, 95.5 %, followed by laptop, 80.8 % and desktop computer, 54.1 %. This finding is to be expected given that almost every adult in the UK and Ireland now uses / owns a mobile phone (Statistica.com, 2022a, 2023). The greater use of laptops than desktops could be explained by the increase in working from home that has occurred since the COVID-19 pandemic, with 77.6 % of the participants indicating that they worked from home for at least part of their working week.

The mean number of hours that devices were used for was 9.7 hours which is similar as that found in other studies (Rosenfield, 2016; Ahuja *et al.*, 2021; Zayed *et al.*, 2021). The range of hours used was from 1 to 24, with 81 participants saying they used their devices for ≥12 hours a day and 31 saying they used their devices for ≥16 hours a day. This seemingly very high number of hours that some participants reported using their devices could perhaps be explained by the use of multiple devices simultaneously, for example using a laptop and a desktop or tablet while sitting at their desk and also having their smartphone open (Sheppard and Wolffsohn (2018) reported 87 % of individuals aged 20-29 years use two or more digital devices simultaneously for multiple tasks so this is not an unexpected finding). It would appear also that some device users considered having their device open and available for use was the same as actually using their device, which could mean that hours of use reported by users in other circumstances may not reflect actual device usage at all. To record this more precisely, an objective measurement of device use would be a more accurate way of determining actual screen use. Such objective measurements have been used in other studies, for example Ostrin *et al.* (2018) used a smart watch type device to measure daylight exposure in children and Apple (Apple, Cupertino, CA, USA) iPhones and iPad devices also permit time on their devices to be recorded and a user report to be generated. In their study on the effectiveness of the 20/20/20 rule, Talens-Estarelles *et al.* (2022) found a similar finding where participants in their study reported using devices for an average of 7 hours per day, whereas specially installed software (which monitored their use) recorded an average of just 4 hours per day which would suggest that individuals may tend to overestimate their duration of device use. If device usage software, such as that, was used it may be possible to get a more accurate assessment of their actual device usage.

Of the 401 participants in this study who completed the DEQ-5 questionnaire, 61.8 % had a score of >6; of the female participants 70.7 % had a score >6 and 47.14 % of males had a score >6. This finding is consistent with other studies which show that females are more likely to have dry eye symptoms than males (Salibello and Nilsen, 1995; Schaumberg *et al.*, 2003; Rosenfield, 2016; Zayed *et al.*, 2021). Some recent studies (Akowuah *et al.*, 2021) have considered a score ≥6 in the DEQ-5 to be indicative of dry eye syndrome, if this metric is used in this study, then the percentage of participants would increase to 72.3 %. This indicates that dry eye symptoms amongst device users are pervasive. This is a similar finding to that in other studies where a clear link between DES and dry eye has been established (Rosenfield, 2016). However, the study showed that only 30.2 % of participants used ocular lubricants to relieve their symptoms, while this is higher than the 20.5 % figure found by Portello *et al.* (2012) it is still relatively low. As such the use of correct ocular lubricants needs to be encouraged in symptomatic device users. The optometry profession, given the findings in this study and by Moore *et al.* (2021) that the use of lubricants for the relief of DES was considered to be important by 94.6 % of optometrists, should be in a good position to achieve this.

The results of the DEQ-5 and the CVS-Q are highly correlated (Spearman's correlation r_s=0.60, r_s^2=0.36, P<.00001) indicating a definite link between dry eye symptoms and DES. In addition, there is also good correlation between the findings of the CVS-Q and for the 'self-diagnosing' of DES (Spearman's correlation r_s=0.46, r_s^2= 0.2116, *P*<0.00001). This would indicate that device users are reasonably accurate in self-diagnosing DES. Therefore, if a device user indicates that they think have DES there is a good possibility that they do indeed have it.

Musculoskeletal symptoms were reported by 94.3 % of device users (which is a similar finding to that Basu *et al.* in their 2014 study in India) with 19.2 % reporting them to occur most days. When considering DES these symptoms in device users could be overlooked (as more attention is paid to ocular symptoms), but this finding would appear to confirm that musculoskeletal symptoms are a very common occurrence that deserves attention. Symptoms were more likely in those working from home which could be due to their workstation being less ergonomic than that in a typical office environment.

Ocular symptoms were reported by 89.5 % of respondents, with 34.4 % saying they occurred regularly or very frequently, however when asked to rate how much their symptoms bothered them, only 8.1 % said they were severe enough to affect their work. Working from home was again shown to have a higher likelihood of symptoms than those who did not work regularly from home. Both CVS-Q results and DEQ-5 results were highly positively correlated with the participants bother score as were muscular symptoms, showing that while CVS-Q and DEQ-5 are designed to measure ocular symptoms of DES they are also a good predictor of non-ocular symptoms.

The finding that only 8.1 % of participants considered their symptoms to be significant enough to affect their work is novel and important as it indicates that while DES is prevalent in this cohort of device users, in the vast majority of those who ‘suffer’ from it, it appears to have no significant effect on them. This finding is different to that reported in other studies (Sheedy, Hayes, *et al.*, 2003; Portello *et al.*, 2012), where device user’s symptoms were reported to have a more significant effect on their performance. While this type of questioning has not been validated or shown to be repeatable, if this finding were to be repeated in subsequent studies, it could indicate that the significance of DES on the typical device user has perhaps been over estimated.

Taking regular breaks was the means used by most respondents to reduce their DES symptoms (62.3 %). This has been shown to significantly reduce DES symptoms in several studies (Misawa *et al.*, 1984; Izquierdo *et al.*, 2007) and device users should be advised of its benefits especially when using devices for many hours. Looking away from the screen was another method used to reduce symptoms by many participants (49.4 %); this latter strategy combined with taking breaks was found by Reddy *et al.* (2013) to further reduce symptoms. Many optometrists advise their patients to use the 20/20/20 strategy (where after 20 minutes of device use, the user looks at objects 20 feet away for 20 seconds) which combines both taking breaks and looking into the distance and this has been found to be effective in reducing DES and dry eye symptoms when using digital devices (Talens-Estarelles, Cerviño, *et al.*, 2022). As part of this research programme, Moore *et al.* (2021) reported that 98.2 % of optometrists considered taking breaks and looking into the distance to be important in reducing symptoms of DES in device users and as such those attending their optometrist for advice on dealing with DES should be reassured that they will be informed of the importance of this strategy.

Many respondents also adjusted their screen settings, workplace setup and environment to reduce the occurrence of DES symptoms. Again, this has been shown to reduce DES (Von Stroh, 1993; Sheedy, 1995, 1996; Tribley *et al.*, 2011) and device users should be educated to know how this can be done to reduce DES. Moore *et al.* (2021) showed that 97 % of optometrists considered giving advice on the office environment and workstation setup to be important and should be able to advise their patients on how to do this. However, given the high numbers of device users who reported working regularly from home, this could be difficult as many users may not be able to adjust their ‘home-office’ setup to that which is optimal or recommended for the reduction of DES. As such employers should consider advising their employees who regularly work from home how to best to set up their workspace to reduce the occurrence of DES. The College of Optometrists (UK) and the Association of Optometrists Ireland could produce and circulate a document with advice on how this could be done thereby further enhancing the role of the profession in managing DES with the public.

Three hundred and four or 75.8 % of participants would expect their optometrist to provide advice to them during their eye examination about DES which is a significant finding for the optometry profession as it shows that patients / clients expect optometrists to be knowledgeable in this area and would value their opinion in dealing with an ever-increasing problem. As part of this programme of research, Moore *et al.* (2021) showed optometrists appreciate the difficulty their patients can have with DES and are ready to provide advice and help to reduce its symptoms. Of the participants who considered themselves to be suffering from DES, 70 % (170) reported having had an eye examination in the last two years which could indicate that this cohort are aware of the help they can get from their optometrist with respect to DES and as such attend for regular eye examinations.

Almost half of respondents, 44.6 %, used single vision spectacles when using their device(s) with 23.4 % using multifocal spectacles. No spectacles were used by 27.2 % of respondents, this latter figure could be accounted for by the fact that 33.9 % of the respondents were under the age of 40 and as such would not be at an age where presbyopia is evident (Millodot and Millodot, 1989; Pointer, 1995). Self-diagnosed DES was high in those who used ready-made reading spectacles, 73.3 % (albeit from a small sample size) which could be accounted for by the lack of astigmatic correction in this type of correction given that astigmatism has been shown in previous studies to cause significant visual discomfort and reduced productivity in device users (Wiggins and Daum, 1991; Wiggins *et al.*, 1992). Only 11 % of respondents used specialised 'computer' spectacles to reduce their DES symptoms and none mentioned using 'blue light' filtering spectacle lenses. Given the publicity (notably on social media platforms) about the use of these 'blue light' filtering spectacle lenses (especially since / during the COVID-19 pandemic) this is a surprising finding. Moore *et al.* (2021) found that the use of specialist spectacle lenses in DES management was an area where optometrists lacked confidence (11.3 % reporting they did not know how important it was to advise on this type of correction and only 34.2 % felt they were extremely or very important in managing DES). With a range of specialist lens types now available for both pre-presbyopic and presbyopic digital device users this could represent an area where further education would be of value to the optometry profession which in turn could provide device users with advice on whether these specialist lens types are suitable for them.

As with all research this study has some shortcomings. While the minimum number of valid respondents required was exceeded, the study could have benefited from a more equal gender and age balance (given the suspected effect of gender and age on the prevalence of DES). Respondents were predominantly office workers and, as such, not fully representative of the entire UK or Irish workforce. Therefore, it is possible that different results may have been obtained if workers in other working environments who also use digital devices on a daily basis, such as factory floors, retail etc. were questioned. It was also difficult to quantify the accurate usage of devices with many users apparently equating device usage with the availability of device use (as stated earlier an objective measurement of device use would have been of benefit in this study and should be considered for future work in this area). As with all studies, those who have an interest in DES, or who believe they have or suffer from DES, may be more motivated to complete the study than those that do not. Questions could also have been asked about the number of years the participants have been using digital devices as part of their work and some details could have been requested about their workstation setup, such as viewing distance, screen height, screen position with respect to windows etc. and while this was considered, the research team felt it would have presented the participant with a much longer and cumbersome survey and that may have had negative consequences with some abandoning the survey before it was fully complete.

Further work in the area of DES in an older population would be of benefit, as in this study only 11.7 % of participants were aged over 60, so specific problems relating to this age cohort and DES may not have been detected.

3.5 Conclusion

This study provides a valuable insight into DES in digital device users in Ireland and the UK and is the first of its kind to be completed. It shows, that while the level of DES is high in device users, at 62.6 %, the actual effect or consequences of it on them does not appear to be significant. For the first time it shows a clear correlation between the DEQ-5 and CVS-Q questionnaires. It shows that device users expect their optometrist to advise them on DES and to be knowledgeable of the condition and as such these findings should encourage the profession to educate it's members further in this area.

CHAPTER 4

Digital Eye Strain and Clinical Correlates in Older Adults

4.1 Introduction

The substantial growth in use and ownership of digital devices over recent years has been well documented. It is accepted that the majority of adults, and increasingly children, spend significant amounts of time on a daily basis using digital devices for professional, educational and / or lifestyle purposes (Chen and Adler, 2019; Madigan *et al.*, 2019). The adoption of handheld screen devices, such as smartphones, tablets and e-readers, has increased in the population as a whole (Mylona and Floros, 2022) with 83 % of adults aged 50 to 64 years and 61 % of adults aged 65 years and older now owning a smartphone (Pew Research Center, 2022).

At the beginning of 2020, Ofcom research (Ofcom, 2020) highlighted that adults in the UK were spending over 25 hours per week online, since the COVID-19 pandemic time spent online has increased further with adults now spending over 4 hours per day online (Ofcom, 2020). It should be noted that 'time online' does not encompass all screen time, and estimates suggest that typical adults spend around 40 % of their waking hours viewing digital device screens (Ofcom, 2020).

Studies in this field have been done on working age adults (Rosenfield, 2011; Portello *et al.*, 2012) and in children (Mohan, Sen, Shah, Jain, *et al.*, 2021), but there is a paucity of research of the effects of DES in an older population (aged 60 years and above). DES is associated with dry eye (Rosenfield, 2011; Moon, Lee and Moon, 2014; Park *et al.*, 2014) and device use requires the operator to have adequate near vision ability to view the screen which is often at a distance of less than 50 cm (Rosenfield *et al.*, 2009; Kim *et al.*, 2017; Sheppard and Wolffsohn, 2018). Older adults are more prone to dry eye (Wang *et al.*, 2020), with the TFOS DEWS II report identifying age as a 'consistent risk factor' for dry eye (Craig, Nelson, *et al.*, 2017), with each decade of life being associated with a 24 % increase in the odds of developing dry eye disease (Wang *et al.*, 2020) and older adults will be presbyopic (Millodot and Millodot, 1989; Pointer, 1995). While it may be reasonable to assume that this age cohort will be more susceptible to DES than a younger aged cohort, there is little evidence to support this assumption.

Given the high prevalence of DES in the general population, it is likely that optometrists will be examining patients with DES on a very regular basis and as such it is important to know if older adults (aged 60 years plus) will experience different problems than those of a younger cohort. This will enable the optometrist to give better advice to them and may result in a reduction of symptoms and therefore an improvement in their quality of life. As part of this programme of study, the research group (Moore *et al.*, 2021) found that optometrists recognise DES as a significant issue and are willing to discuss and advise their patients about it and therefore further research into DES in this age group would be of benefit to the profession as a whole.

The aim of this study is to evaluate the screen time habits, associated symptoms and clinical characteristics of an older population (60 years and over) drawn from primary care optometry.

4.2 Methods

The study received a favourable opinion from the Health and Life Sciences Research Ethics Committee at Aston University (#21007) and was conducted according to the tenets of the Declaration of Helsinki. Before entering the study, each participant was required to provide informed consent after reading the participant information and transparency statement.

Consecutive patients aged 60 years and over attending for an eye examination at a primary care optometric practice in Dublin, Ireland, were invited to participate. Those who used a digital device for at least 1 hour per day were eligible to participate. All empirical data were obtained by the same investigator (an Irish and UK registered optometrist). There are approximately 1.04 million adults over the age of 60 years in Ireland (Age Action Ireland, 2022). As mentioned previously, sample size calculation is important in all aspects of research as using an adequate sample size will help in the collection of high quality data which is more reliable and valid for the cohort being studied (Bartlett *et al.*, 2001). An appropriate sample size renders the research more efficient, represents the population better and allows for confidence in conclusions drawn from the data (Faber and Fonseca, 2014; Andrade, 2020). For 95 % confidence and a ± 5 % margin of error in responses, a required sample size of 384 responses was determined for the study (Qualtrics, 2020).

Age, gender and ethnic group were recorded. Due to the reported link between smoking and dry eye (Xu *et al.*, 2016; Narnoli *et al.*, 2021), smoking status (had the participant smoked in the last month) was also recorded. The study gathered information regarding the participant's use of digital devices, the types of devices used and duration of use. Participants were also asked to indicate which was their primary digital device i.e., device used for the most amount of time daily. Best corrected binocular logMAR distance acuity was recorded using a Thomson electronic test chart (Thomson Software Solutions, UK). Near vision adequacy for reading and device use, along with the required near addition and viewing distance, was also recorded.

Participants were asked to indicate which type of optical correction they used generally and which they used when using their primary digital device. A list of symptoms typically associated with DES (Blehm *et al.*, 2005; Rosenfield, 2016) was then presented to the participant and they were asked to indicate which, if any, they experienced when using digital devices, and then to say if they felt they suffered from DES. Next, participants completed the 5 items from the validated Dry Eye Questionnaire (DEQ-5) (Chalmers *et al.*, 2010). Participants also completed all items from the validated Rasch-analysed Computer Vision Syndrome Questionnaire (CVS-Q) designed to measure visual symptoms related to computer use in the workplace (del Mar Seguí *et al.*, 2015).

Following initial development of the questionnaire by academic optometrists with research interests in DES, a pilot study of eligible participants was undertaken to determine if it were feasible to undertake such a study in a primary care optometric practice without causing excessive disruption (to the day-to-day functioning of the practice). In so far as was possible, participants in the pilot were from different age groups over 60 and balanced between male and female. No disruption occurred in the practice during the pilot and as such the study proceeded as planned.

The study was carried for 16 weeks between June 2022 and October 2022. Data collected were exported into an Excel spreadsheet for analysis. Statistical analysis of the data using the Kolmogorov-Smirnov test (K-S) showed the data in this study was not normally distributed for participants age (P=0.001, D=0.10125), DEQ-5 score (P=0.001, D=0.09660) and CVS-Q score (P=0.001, D=0.109746) and therefore non-parametric tests, such as Spearman's rank-order correlation coefficient and Mann-Whitney U test were used throughout to analyse the data. A p-value of <0.05 was considered significant throughout.

4.3 Results

Profile of the participants

Four hundred and one participants completed the study, of those 245 were female (61.1 %) and 156 were male (38.9 %). The median age of the participants was 71.0 (IQR 65.08-79.91); 99.5 % were White-Irish and 0.5 % were Asian-Irish.
When asked if they had smoked in the last month, 17.7 % said they had and 82.3 % said they had not.

Daily device type and usage

The device types that were used by most participants were smart phones (93.3 %) and tablet (72.5 %), desktop computers were used the least (10 %). A full breakdown of device types used is shown in table 4.1 below. When asked which was their primary digital device (device used for longest duration on a daily basis), 41.4 % said tablet, 26.7 % said smartphone, 15 % said laptop computer, 9.2 % said electronic 'e' reader and 7.7 % said desktop computer. The median number of hours of device use was 4 (IQR 2-5). Spearman's rank-order correlation coefficient showed a significant negative relationship between age and hours of use of digital devices (r_s= -0.557, r_s^2=0.3102, P <0.00001).

Digital device type	Percentage of participants using device type
Smartphone	93.3 %
Tablet	72.5 %
Laptop computer	27.9 %

E reader	29.1 %
Desktop computer	10.0 %

Table 4.1: Percentage of participants which used different device types (participants could select more than one device type).

Visual Acuity

The minimum LogMAR distance acuity recorded was -0.1 (6/5 Snellen equivalent) and the maximum was 0.4 (6/15 Snellen equivalent). The median and mode were both 0 (6/6 Snellen equivalent). Spearman's rank-order correlation coefficient showed a significant negative relationship between hours of use of digital devices and distance acuity (r_s= -0.413, r_s^2= 0.1705, P <0.00001).

Near vision adequacy ranged from N10 to N5 with the latter recorded in 55.6 % of participants, N6 in 37.9 %, N8 in 5.7 % and N10 in 0.7 % of participants. The median near addition was +2.50 dioptres (D) (range 0-4 D, IQR 2.25-3.00 D). The median near working distance was 35 cm (range 20-45 cm, IQR 33-40 cm). Spearman's rank-order correlation coefficient showed a significant negative relationship between hours of use of digital devices and near acuity (r_s= -0.324, r_s^2= 0.1049, P <0.00001).

Primary device acuity ranged from N12 to N5 with the latter recorded in 35.9 % of participants, N6 in 50.6 %, N8 in 11.5 %, N10 in 1.7 % and N12 in 0.2 % of participants. The median device addition was +2.50 dioptres (range 2.50-4.00 D, IQR 2-3). The median device working distance for their primary device was 35 cm (range 20-70 cm, IQR 35-40 cm). Spearman's rank-order correlation coefficient showed a weak positive relationship between hours of use of digital devices and primary device near acuity (r_s= 0.0905, r_s^2= 0.0081, P=0.0702).

Type of visual correction used

Single vision spectacles were used by most participants for general use and for their primary digital device, 53.1 % and 61 % respectively. Participants who used bifocals for general use were the most likely group to also use a different method of correction for their device with 50 % also using single vision spectacles, of those who wore varifocals for general use, 41 % also used single vision spectacles when using their primary device.

Symptoms while using digital devices

Seventy one percent of participants reported symptoms when using digital devices. Tired eyes were the symptom most selected by participants, 64.8 %, followed by dry eye symptoms 33.2 %; 28.7 % of the participants said they experienced no symptoms when using their devices.

A full breakdown of the symptoms is shown in table 4.2 below.

Symptoms experienced using digital devices	**n (%)**
Tired eyes	260 (64.8 %)
Dry eyes	133 (33.2 %)
Focusing problems	117 (29.1 %)
Visual / eye strain	115 (28.7 %)
None	115 (28.7 %)
Muscle pain (arm/shoulder/neck etc..)	100 (24.9 %)
Headaches	72 (24.9 %)
Other	1 (0.25 %)

Table 4.2: Symptoms experienced when using digital devices in descending order (n=401)

When asked if they thought they suffered from digital eye strain, 33.2 % indicated that they thought they did and 66.8 % said they did not think so.

DEQ-5

The median DEQ-5 score was 6 (IQR 4-8) with a range of 0 to 14; 49.1 % of participants returned a score of >6, 53.9 % of females had a score >6 and 41.6 % of males had a score >6. Spearman's rank-order correlation coefficient showed a minor negative relationship between DEQ-5 score and age (r_s= -0.1387, r_s^2= 0.0192, P=0.005639); DEQ-5 score and hours of device use showed a weak positive relationship (r_s= 0.3001, r_s^2= 0.09, P<0.00001) as shown in figure 4.1 below.

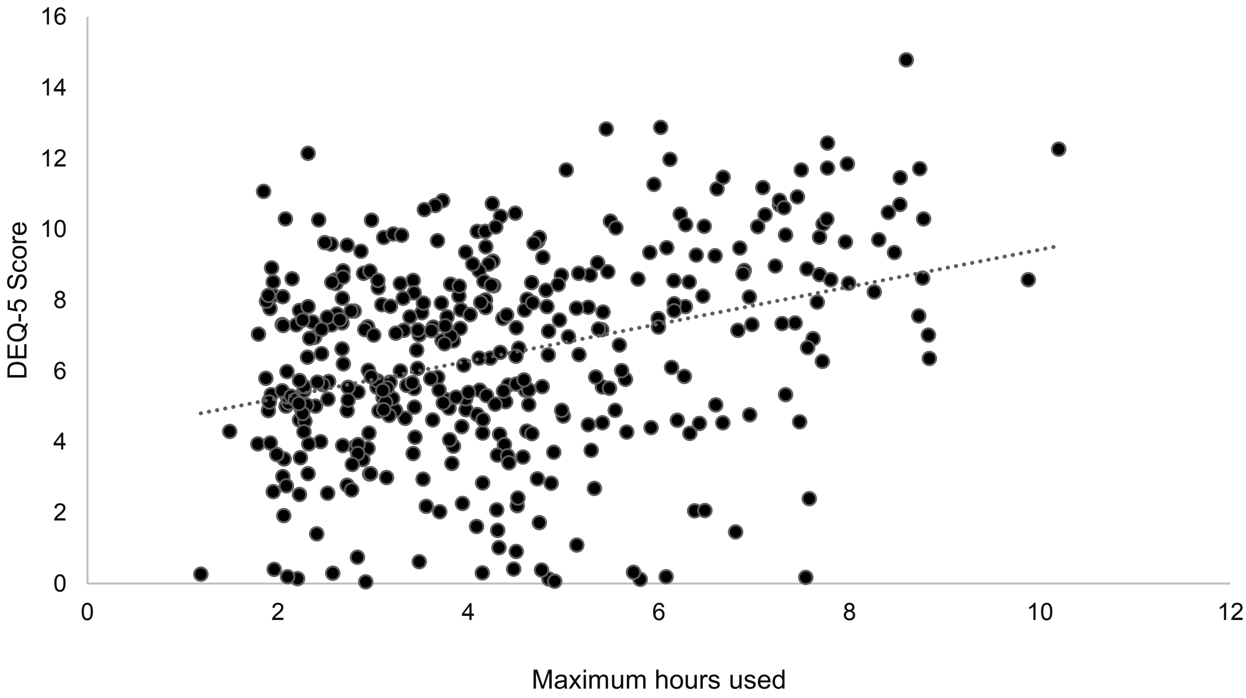

Figure 4.1: Correlation between participants DEQ-5 score and daily hours of device use, r_s= 0.3001, r_s^2= 0.09, *P*<0.00001. Data have been jittered to improve visibility of overlapping data points.

Females (n=245) had a median DEQ-5 score of 7 (IQR 5-8), males (n=156) had a median DEQ-5 score of 5 (IQR 4-8). A Mann-Whitney U test showed that the median DEQ-5 score was significantly higher in females than males (*U*=15960.5: *P*=0.00544).

Of the 71 (17.7 %) participants who said they had smoked in the last month, 46.5 % had a DEQ-5 >6 while 53.5 % had a DEQ-5 score ≤6. A Mann-Whitney U test showed that the median DEQ-5 score was similar in smokers and non-smokers (*U*=11514.0: *P*=0.844739). One hundred and seventy respondents, 42.3 %, said they experienced eye discomfort sometimes or frequently on a typical day, 15.7 % respondents said it never occurred. Regarding eye dryness, 36.6 % respondents reported it occurring sometimes or frequently on a typical day in the last month, with only 10.2 % saying it never occurred. Seventy-nine (19.7 %) respondents said that their eyes looked or felt excessively watery sometimes or frequently on a typical day during the last month with 24.9 % saying they never did. DEQ-5 scores differed across the primary device used by the participant, 18.2 % of participants who stated that their primary digital device was a tablet had a DEQ-5 >6 whereas only 3.49 % of participants who stated that their primary digital device was an electronic 'e' reader had a DEQ-5 score >6.

Of the 33.2 % of participants who mentioned having 'dry eye symptoms' when using digital devices, 84.9 % had a DEQ-5 score >6, and of the 28.7 % of participants who said they had no symptoms while using their digital devices, only 7.82 % had a DEQ-5 score >6. Of the 133 (33.1 %) participants who believed that they had DES, 92.5 % returned a DEQ-5 score >6, while only 27.6 % of the 268 who did not believe they had DES had a DEQ-5 score >6. Figure 4.2 below shows the breakdown of symptom prevalence reported by participants when answering the DEQ-5 questionnaire.

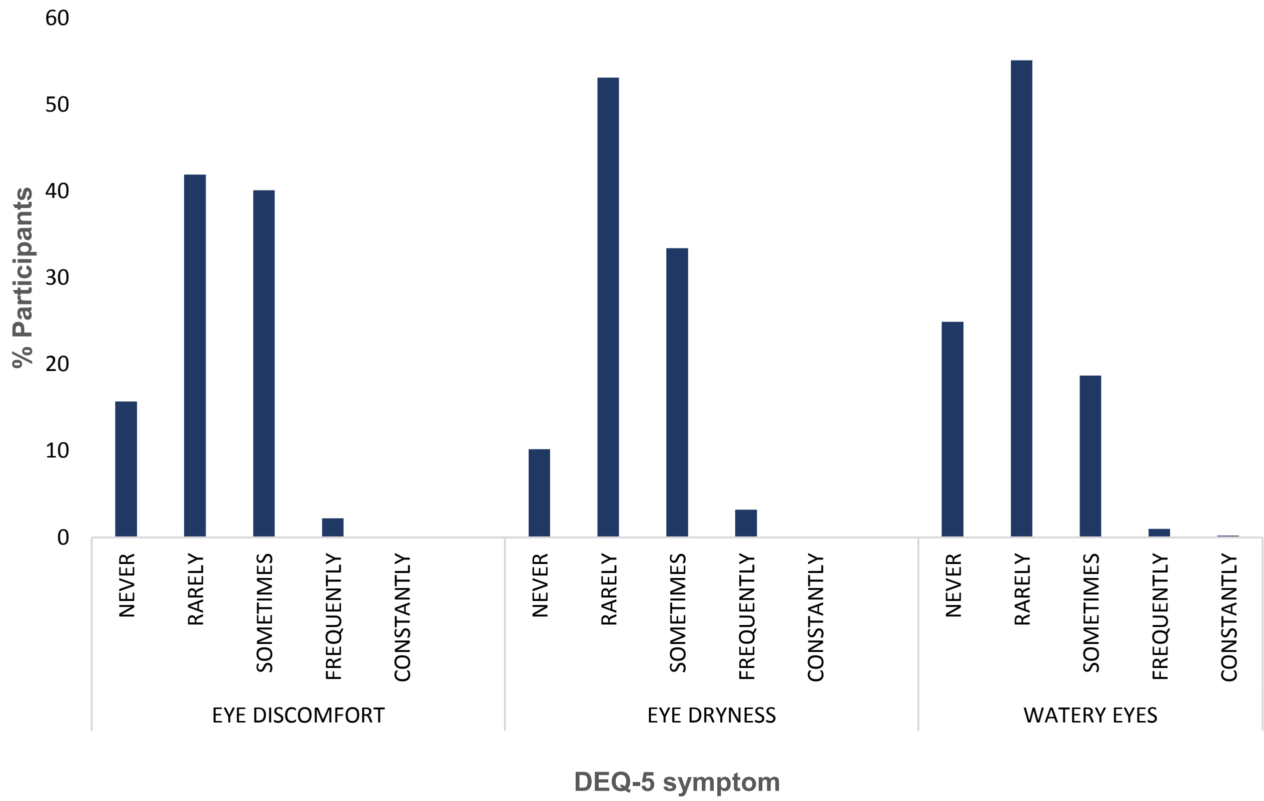

Figure 4.2: Occurrence of symptoms as reported on the DEQ-5 questionnaire on a typical day during the last month (n=401).

Computer vision syndrome questionnaire (CVS-Q)

Of the 401 participants, 51.6 % returned a score ≥6 for the CVS-Q, the median score being 6 (IQR 3-7), with a range of 0 to 18; 55.9 % of females had a CVS-Q score ≥6 and 44.9 % of males had a CVS-Q score ≥6. Spearman's rank-order correlation coefficient showed a very weak negative relationship between CVS-Q score and age

(r_s= -0.1381, r_s^2= 0.019, P=0.005639); CVS-Q score and hours of device use showed a positive relationship (r_s= 0.3145, r_s^2= 0.0989, P<0.00001) as shown in figure 4.3 below.

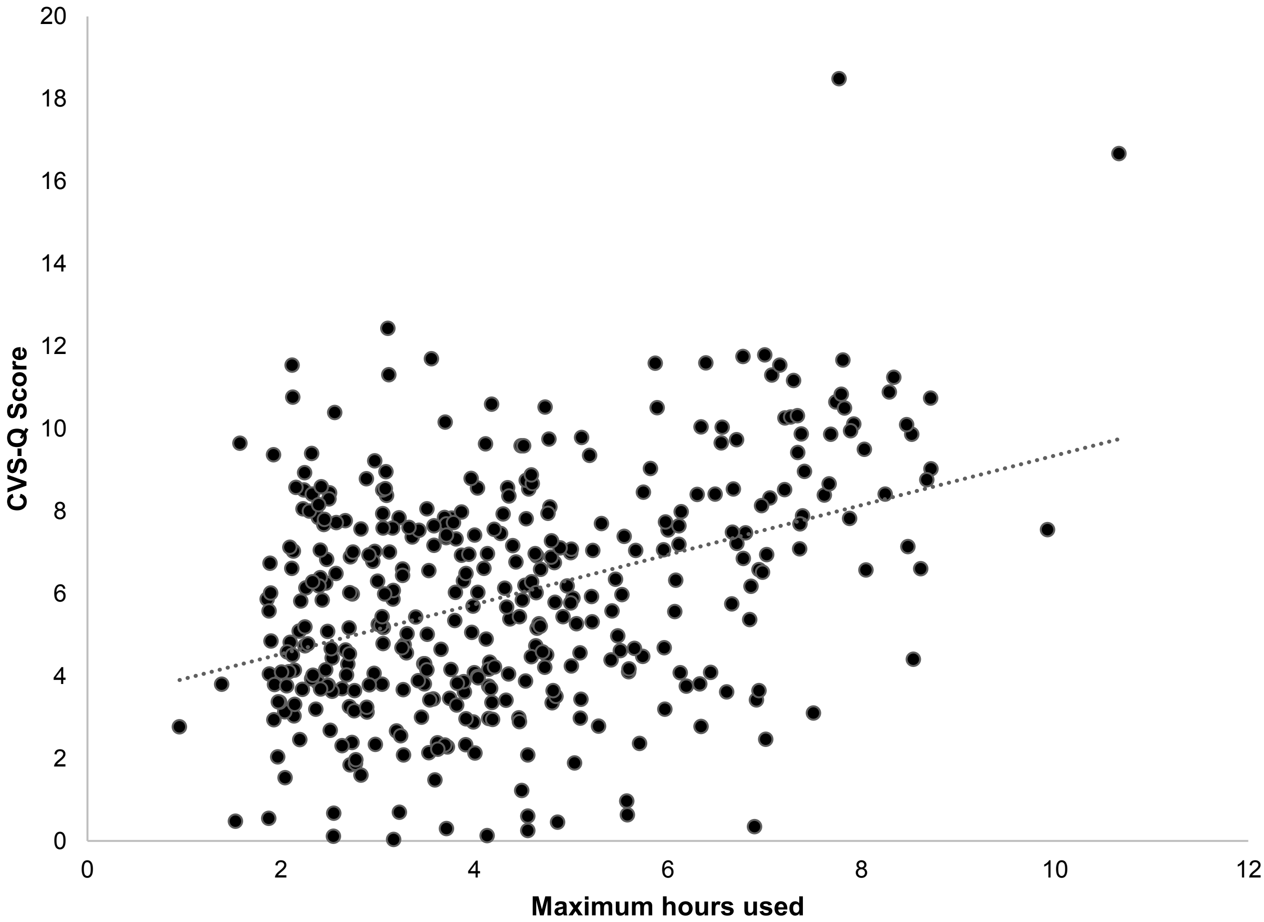

Figure 4.3: Correlation between participants CVS-Q score and hours of device use, r_s= 0.3145, r_s^2= 0.0989, P<0.00001. Data have been jittered to improve visibility of overlapping data points.

Females (n=245) had a median CVS-Q score of 6 (IQR 4-8), males (n=156) had a median CVS-Q score of 5 (IQR 3-7). A Mann-Whitney U test showed that the median CVS-Q score was significantly higher in females than males (U=16620.5: P=0.027835). Of the 71 (17.7 %) participants who said they had smoked in the last month, 53.5 % had a CVS-Q ≥6 while 46.5 % had a CVS-Q score <6. A Mann-Whitney U test showed that the median CVS-Q score was similar in smokers and non-smokers (U=11418.0: P=0.798723). Of the 133 participants who said they thought they had DES, 96.24 % returned a CVS-Q score ≥6, and of the 268 who said they did not think they had DES, 29.47 % returned a CVS-Q score ≥6. Spearman's

rank order correlation showed a significant correlation between CVS-Q ≥6 and the participant thinking that they have DES (r_s=0.6979, r_s^2= 0.4870, P<0.00001).
The symptoms most frequently selected on the CVS-Q (as either 'occasionally' or 'often / always') were 'feeling that sight is worsening' (n=272, 67.8 %), 'dryness' (n=261, 65.1 %) and 'heavy eyelids' (n=233, 58.1 %). The three least selected symptoms were 'coloured halos around objects' (n=7, 1.7 %), 'double vision' (n=14, 3.5 %) and 'blurred vision' (n=59, 14.7 %). A full breakdown of the frequency of symptom selected is shown below in figure 4.4.

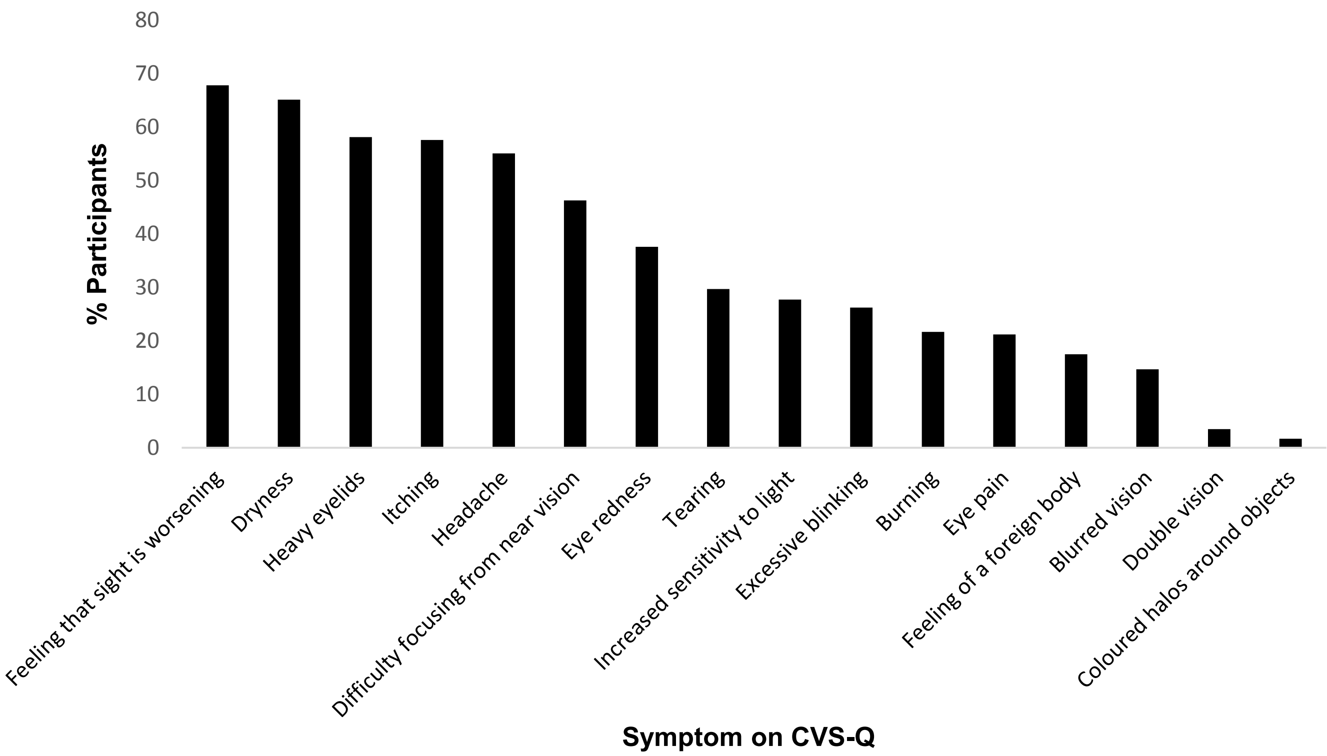

Figure 4.4: Percentage of participants selecting each symptom type in descending order on CVS-Q (n=401)

Participants DEQ-5 score and CVS-Q scores are highly positively correlated with Spearman's rank-order correlation coefficient r_s=0.81, r_s^2= 0.6561, P <0.00001 (figure 4.5 below).

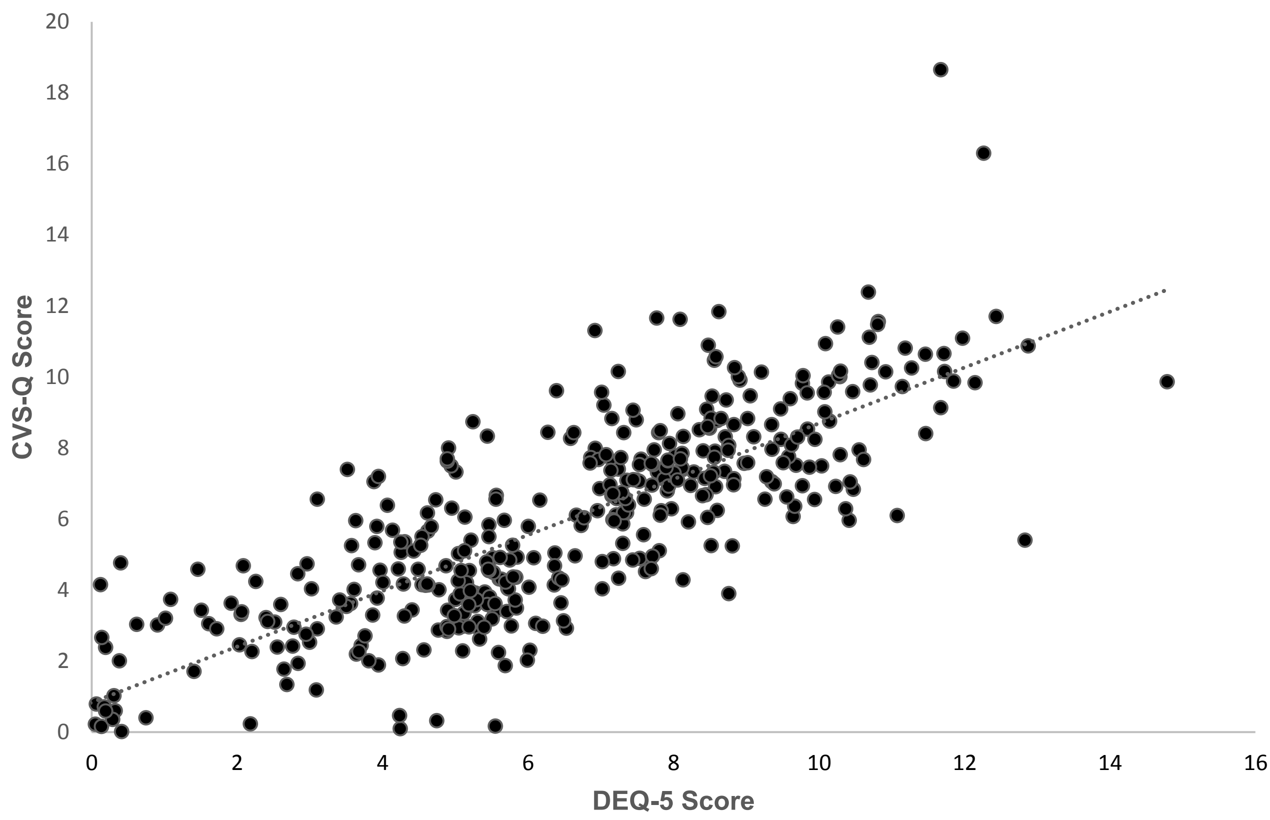

Figure 4.5: Correlation between DEQ-5 and CVS-Q scores, r_s= 0.81, r_s^2= 0.6561, *P* <0.00001. Data have been jittered to improve visibility of overlapping data points.

4.4 Discussion

This prospective study on the self-reported screen habits, associated symptoms and clinical correlates of DES in an older population presenting for routine optometric care was the first of its kind and included participants with a broad range of device usage, various DES signs and symptoms and optical corrections. It appears to be, at the time of writing, the first set of published data on the occurrence of DES in an older (≥60 years) population and its effects on them. It also studied the link between DES and dry eye and looked for links between device use, device type and visual acuity with DES. It demonstrated that it was possible to conduct a detailed study in an optometric practice with minimal disruption. Research is the core component of evidence based healthcare and regulatory authorities are keen to increase the scope and capacity of healthcare research, to build evidence-based practice and improve patient care (Taylor *et al.*, 2022). There are lots of opportunities for community optometrists to carry out research in their practice and this study adds to the body of literature showing that it can be done.

The study included 401 participants which represents a larger cohort than that of other published studies in this area; Mylona and Flores (2022) included120 participants in a study of presbyopia and DES, Ahuja *et al.* (2021) included 141 participants in a study on the prevalence of DES in an Indian population, Zayed *et al.* (2021) in a study of DES in Tanta University (Egypt) included 108 participants, Sanchez-Brau *et al.* (2021) in a study of DES in presbyopic workers included 68 participants, Choi *et al.* (2018) in a study of smartphone use and the ocular surface included 80 participants and Cagnie *et al.* (2017) in a study of DES in VDU workers included 35 participants (Cagnie *et al.*, 2017; Choi *et al.*, 2018; Sánchez-Brau *et al.*, 2020; Ahuja *et al.*, 2021; Sánchez-Brau *et al.*, 2021; Zayed *et al.*, 2021; Mylona and Floros, 2022).

Based on a CVS-Q score ≥6 the study found 51.6 % of this cohort of adults aged ≥60 years would be classified as having DES. This is a significant finding for the profession, as it implies that over half of patients in this age cohort who regularly use a digital device (≥1 hour per day) and who attend for a routine eye examination can be expected to have symptoms consistent with DES, and as such their optometrist should be able to help them deal with the syndrome. As an earlier part of this programme of research found that 88.9 % of optometrists in the UK and Ireland considered DES to be an important concern and over 90 % reported that they felt confident in the discussion and management of the condition with their patients (Moore *et al.*, 2021). Therefore, patients should feel reassured that if they present with symptoms of DES, their optometrist should be able to assist them in its management.

The device used for the longest duration on a daily basis by this cohort was a tablet, however the device type which was used by most participants was the smartphone. This is not a surprising finding given that 74.6 % of adults in Ireland now own a smartphone (Statistica.com, 2023) and a similar finding was reported by Mylona et al, (2022) where 61 % of those aged 65 years and older owned a smartphone but only 53 % owned a tablet. However, it does show that the participants preferred to use a tablet over a smartphone, this could be explained by the fact that the screen in the former is larger thereby making it easier for the user to see. Smartphones place a particular strain on the user especially when they must change their focus or attention from the device to other objects in their environment and this will be especially difficult for a presbyopic device user (Bababekova *et al.*, 2011; Long *et al.*, 2017) and smartphones may be associated with considerable tear film instability (Choi *et al.*, 2018).

A negative correlation was found between hours of device use and age (r_s= -0.324, r_s^2= 0.105, *P* <0.00001). Greater hours of use showed a positive correlation with having a DEQ-5 score >6 (r_s= 0.3001, r_s^2= 0.09, *P*<0.00001) and having a CVS-Q ≥6 (r_s= 0.3145, r_s^2= 0.09891, *P*<0.00001), this finding is similar to that found in other studies where increased use of devices was linked to increased occurrence of symptoms of DES (Portello *et al.*, 2012; Tauste *et al.*, 2016; Lin *et al.*, 2017; Omran Al Dandan *et al.*, 2020; Talens-Estarelles *et al.*, 2021; Talens-Estarelles, García-Marqués, *et al.*, 2022). However, it is interesting and perhaps expected (due to the reduced number of hours they use their devices for) to note that there was a negative correlation between age and positive results for both the DEQ-5 and CVS-Q indicating that age is not a good predictor of the likelihood of DES in this age cohort whereas hours of use is (this is a similar finding to that of Hayes *et al.* in their 2007 study).

The study showed that participants with better levels of distance and near acuity used devices for longer periods than those with poorer acuity (r_s= -0.413, r_s^2= 0.1705, *P* <0.00001, r_s= -0.324, r_s^2= 0.1049, *P* <0.00001 respectively) which is not surprising given that device use, especially when prolonged, does require good acuity (Bababekova *et al.*, 2011). Munshi *et al.* (2017) also found that device users with reduced levels of acuity, due to age or disability, experienced more significant DES symptoms than those with better levels of acuity, and since acuity declines with age (Gittings and Fozard, 1986) this would not be an unexpected finding. A finding such as this shows that when encountering patients with reduced acuity, special efforts should be made by the optometrist to assist them with using their digital devices, such as advice on increasing font size on the device, using high addition spectacle prescriptions, advice about suitable working distances and illumination.

In a similar finding to that of Boccardo *et al.* (2021) the working distances used by the participants in this study for general reading and device use were broadly similar (median in both cases being 35 cm, IQR 33 - 40 cm, IQR 35 – 45 cm respectively), indicating that for most participants a separate pair of 'computer / device' spectacles is not necessary. This could account for the low percentage of participants who used 'occupational' spectacles for either near tasks (0.75 %), such as reading printed material, or for device use (4.5 %) and similarly would account for 'single vision spectacles' being the most commonly used means of correction for both general reading (53.1 %) and for device use (61 %).

Tired eyes (64.8 %) and dry eyes (33.2 %) were the symptoms of DES most mentioned by the participants in this study, this is a similar finding to that of Portello *et al.* (2012) 74 % and 61.3 % respectively, Rafeeq *et al.* (2020) 68.7 % for both and Zayed *et al.* (2021) 44.2 % and 47.2 % respectively, where tired eyes / heavy eyelids and dry eyes were amongst the most common symptom of DES reported in their studies of adult device users.

When asked if they thought they had DES, 33.2 % said yes. Interestingly this result differs significantly from that found earlier in this research programme where, in a study on working age adult (≥18 years) device users, 61.8 % said they felt they had DES. In addition, this working age adult group had a DEQ-5 score of >6 in 61.8 % of its participants compared to 49.1 % of the participants in this study. It is possible that this could be due to longer hours of device use in the working age adult group where the median number of hours spent using devices on a daily basis was 9 (IQR 8-11) compared to a median of 4 hours (IQR 2-5) in this study or alternatively, there may be better awareness of the syndrome amongst younger adults.

Female participants had a statistically significant higher DEQ-5 score than males which is a similar finding to that of many studies which indicate a greater occurrence of dry eye in female than male device users, which depending on duration of use, can vary from 3.5 % to as much as 14.5 % (Schaumberg *et al.*, 2003, 2009; Portello *et al.*, 2012; Rosenfield, 2016; Mehra and Galor, 2020). When primary device type was compared to DEQ-5 scores, those using an e-reader had a significantly lower DEQ-5 score than those using other device types. This is a similar finding to that of Köpper *et al.* (2016) who found that high quality LCD displays gave no greater symptoms of eye strain when compared to reading text on paper (Köpper *et al.*, 2016).

In this study, 17.7 % of the participants smoked in the last month which is a higher rate of smokers than that reported in Irish adults, 15.9 %, but less than that reported in EU residents ≥15 years,18.4% (Hoare, Padraig, 2021); this cohort of smokers did not have a higher DEQ-5 score than non-smokers which differs from some studies that report a greater incidence of dry eye in smokers (Xu *et al.*, 2016; Narnoli *et al.*, 2021) but is similar to that found in a study in the Netherlands where there was no greater occurrence of dry eye in current smokers but a higher occurrence in ex-smokers (Vehof *et al.*, 2021). It is possible that this finding is due to the relatively small number of participants who smoked (17.7 %) but as it is a greater percentage than the Irish adult population as a whole it could be a novel finding.

In this cohort, 51.6 % were classified as having DES based on CVS-Q score ≥6; this is similar to that found in other studies, such as that by Portello *et al.* in 2012 (where 50 % of participants had experienced symptoms consistent with DES). However, it is less than that found as part of this research programme (using the same criteria) in a study of working age adult device users where the prevalence was 62.6 %. Research since the COVID-19 pandemic has shown higher rates of DES, Zayed *et al.* (2021) found a prevalence of 82.41 %, Talens-Estarelles et al. (2022) found a prevalence of 73.8 % and Ahuja *et al.* (2021) found a prevalence of 62.4 %. However, it should be remembered that, except for the study done for this research programme, these other studies have used different criteria for the diagnosis of DES, and it would be beneficial to research in this area if all studies used a recognised and validated instrument for the diagnosis of DES, such as the CVS-Q, to make their results comparable.

CVS-Q scores ≥6 and hours of device use are positively correlated which is not surprising as other studies have shown long hours of device use to result in a higher incidence of symptoms of DES (Portello *et al.*, 2012; Talens-Estarelles, García-Marqués, *et al.*, 2022). Females had a higher CVS-Q score than males which is a similar finding to that found by this research team in their study of DES in working age (18 years and older) adults. In a similar finding to that of smokers with DEQ-5 scores, smokers did not have a significantly higher CVS-Q score than non-smokers which would indicate, that in this study, smoking was not a risk factor for DES, this is a similar finding to that of Portello *et al.* (2012) were no significant correlation was observed between smoking and symptoms of DES.

The results of the DEQ-5 and CVS-Q were highly correlated (Spearman's r_s=0.81, r_s^2= 0.6561, P<0.00001) indicating a link between dry eye and DES and certainly an overlap of symptoms. A similar finding was made in this programme of research when investigating DES in working age adult device users (r_s=0.60, r_s^2= 0.36 P <0.00001. While this finding is significant, it is not surprising as 10 symptoms on the CVS-Q are symptoms consistent with dry eye or ocular surface disease (Craig, Nichols, *et al.*, 2017), namely 'burning', 'itching', 'feeling of a foreign body', 'tearing', 'excessive blinking', 'eye pain', 'heavy eyelids', 'dryness' and 'increased sensitivity to light'.

The study has several limitations to consider. There was a gender imbalance between the percentage of females (61.1 %) and males (38.9 %) in the study. Females are more likely to attend for healthcare consultations than males (Bertakis *et al.*, 2000; Redondo-Sendino *et al.*, 2006) and as the participants were seen seriatim this would have been difficult to avoid. However, given the link between dry eye and DES and that females are more likely to have dry eye (Guillon and Maïssa, 2010; Courtin *et al.*, 2016; Craig, Nichols, *et al.*, 2017; Stapleton *et al.*, 2017), an equal gender balance would have been useful. Additionally, almost all of the respondents were white Irish which precluded any study into a link between DES and ethnicity in this cohort, however given that the Irish population is over 90 % white and as participants were seen seriatim this was unavoidable (Central Statistics Office Ireland, 2016). It can also be difficult for people to accurately quantify device use, so hours of device usage as reported by the participants may not be completely accurate. A previous study for this programme of research found that some device users may overestimate hours of device use significantly and it is possible that this cohort may have done the same. Further questions could have been asked about the setup participants have when using their device, such as screen height and positioning with respect to windows etc., and while this was considered by the research team, it was felt that this would have made the study longer and more cumbersome for the participant (and researcher) which could have made it more difficult to complete the study and as such, could have led to a lower participation rate.

4.5 Conclusion

This study provides a valuable insight into the screen habits and likelihood of symptoms of DES in an older population and, is to date, the first of its kind. It shows that the prevalence of DES in older age adult device users is high, at 51.6 %, with a clear link between dry eye and symptoms of DES. Its results will enable optometrists to provide specific advice to this age group on how best to reduce symptoms of DES. It demonstrated that it is possible to conduct a detailed study in an optometric practice without significant disruption and it may encourage other optometrists in community practice to consider embarking on research projects which would be beneficial to the profession.

CHAPTER 5

REPEATABILITY OF THE CVS-Q IN THE DETECTION AND QUANTIFICATION OF DIGITAL EYE STRAIN IN OLDER ADULTS

5.1 Introduction

The Computer Vision Syndrome Questionnaire (CVS-Q) is a validated Rasch-analysed instrument originally designed to measure visual symptoms related to computer / digital device use in the workplace (del Mar Seguí *et al.*, 2015). It has good psychometric properties derived from the Rasch analysis, with sensitivity and specificity values of 75.0 % and 70.2 % respectively for a CVS-Q score of ≥6. Sensitivity and specificity values were calculated on the ability of the instrument to correctly identify a computer worker who reported 'at least one symptom two to three times a week' as suffering from DES (this definition was based on the literature review conducted by the authors when developing the CVS-Q). A 2022 study found sensitivity and specificity values of 80 % and 83.1 % respectively using a diagnostic CVS-Q cut-off score of ≥7 (Cantó-Sancho *et al.*, 2022).

While the CVS-Q was originally developed in Spanish it has been translated into different languages including Italian and Persian (Seguí-Crespo *et al.*, 2019; Qolami *et al.*, 2022) and has been used worldwide in many studies to estimate the prevalence of digital eye strain. Whilst the instrument was designed and validated for use amongst computer workers, different studies have used varying criteria for participants using the CVS-Q as a diagnostic tool for DES and this is shown in table 5.1 below.

Study Name *(Author-Date*)	**Inclusion Criteria**	**Number of Participants**
Effect of contact lens use on computer vision syndrome (Tauste *et al.*, 2016).	Adult civil service office workers, no minimum hours of device use were required.	426 participants, 222 females and 204 males.
Translation, cross cultural adaptation and validation of the CVS-Q into Italian (Seguí-Crespo *et al.*, 2019).	Adult computer users with minimum of 1 hour per day on digital device specified.	40, 17 males and 23 females
Computer-vision symptoms in people with and without neck pain (Teo *et al.*, 2019).	Volunteers aged over 17 years who used a computer for more than 3 hours per day.	167 participants, 119 females and 48 males.

Digital eye strain in a population of young subjects (Veselý *et al.*, 2019)	Two groups of subjects, no minimum age or minimum use of devices specified.	45 participants, gender not specified.
Impact of blue light filtering glasses on computer vision syndrome in radiology residents(Dabrowiecki *et al.*, 2020).	Adult radiology trainees wore BLFL or non-BLFL for 1 week and then swapped, completed CVS-Q at end of their typical working day of 8am to 5pm.	10 participants, 4 males and 6 females.
Prevalence of computer vision syndrome and its relationship with ergonomic and individual factors in presbyopic VDT workers using progressive addition lenses (Sánchez-Brau *et al.*, 2020).	Presbyopic computer workers with a minimum daily use of 4 hours 5 days a week.	144 participants, 47 females and 97 males.
An investigation of low power convex lenses (adds) for eye strain in the digital age (Yammouni and Evans, 2020).	Aged between 16 and 40 years, minimum 6 hours use of devices per week with significant symptoms of DES (CVS-Q score ≥6).	107 participants, 68 females and 39 males.
Computer vision syndrome prevalence according to individual and video display terminal exposure characteristics in Spanish university students (Cantó-Sancho *et al.*, 2021).	Spanish university students, no minimum use of devices was specified.	244 participants, 139 females and 105 males.
Digital eye strain and its risk factors among a university student population in Jordan: A cross sectional study (Gammoh, 2021).	Randomly sampled students in Jordanian university aged between 18 and 24 years, no minimum device use specified.	382 participants, 233 females and 149 males.
Computer vision syndrome in presbyopic digital device workers and progressive lens design (Sánchez-Brau *et al.*, 2021).	Presbyopic digital device users who used a device for more than 4 hours per day in work at least 5 days a week.	69 participants, 26 females and 43 males.
Effects on the ocular surface from reading on different smartphone screens: A prospective randomized controlled study (Yuan *et al.*, 2021).	Adult college students who read for 2 hours from different smartphone screens.	119, 78 females and 41 men.
Digital eye strain: prevalence and associated factors among information technology professionals, Egypt (Zayed *et al.*, 2021).	IT workers who used a device for a minimum of 3 hours per day and had been using it for at least 1 year.	108 participants, 68 females and 40 males.
Computer vision syndrome in healthcare workers using video display terminals: an exploration of risk factors (Artime-Ríos *et al.*, 2022).	Physicians, surgeons, nurses and nursing assistants who worked in two Spanish hospitals, no minimum use of devices was required.	622 participants, 492 females and 132 males.
Rasch-validated Italian scale for diagnosing digital eye strain: The CVS-Q (Cantó-Sancho *et al.*, 2022).	Italian computer workers, average daily use of computers was 5.85 hours ± 1.53.	241 participants, 155 females and 86 males.
Computer-vision syndrome in medical students from a private	Medical students. No other criteria specified.	228 participants, 163 females and 65 males.

university in Paraguay: A survey study (Coronel-Ocampos *et al.*, 2022).		
Randomised controlled trial of an accommodative support lens designed for computer users (Del Mar Seguí-Crespo *et al.*, 2022).	Adults aged between 18 and 40 years, who spend at least 2 hours viewing a computer display per day.	90 participants, 54 females and 36 males.
A case study of digital eye strain in a university student population during the 2020 COVID-19 lockdown in South Africa: evidence of an emerging public health issue (Munsamy *et al.*, 2022).	Randomly sampled university students who had an email account, no minimum use of devices was specified.	297 participants, 76 females and 214 males.
Validation of the digital eye strain questionnaire and pilot application to online gaming addicts (Mylona *et al.*, 2022).	Ophthalmic outpatient department in two hospitals in Greece, between 18 and 45 years, no minimum use of devices specified.	150 participants, 56 females and 94 males
Translation, cross cultural adaptation and validation of the CVS-Q into Persian (Qolami *et al.*, 2022).	Adult computer users with minimum of 1 hour per day on digital device specified.	102, gender not specified.
Dry eye-related risk factors for digital eye strain (Talens-Estarelles, García-Marqués, *et al.*, 2022).	Anonymous online study of university students. No minimum use of devices required. Classified as 'DES' if CVS-Q ≥6 (628) or non-DES if CVS-Q <6 (222)	851 participants, 534 females and 317 males.
Real time blink detection as an indicator of computer vision syndrome in real-life setting: An exploratory study (Lapa *et al.*, 2023).	University students aged 25 years or younger with minimum of 4 hours per day of computer work enrolled in a scientific writing task for the whole period of data collection.	11 participants, 9 females and 2 males.

Table 5.1 Previously published studies which have used the Computer Vision Syndrome Questionnaire (CVS-Q) arranged in chronological order (DES='Digital eye strain', BLFL='Blue light filtering lenses', VDT='Visual display terminal').

As can be seen from table 5.1, prior to this programme of research, the CVS-Q has not been used to exclusively assess DES in older age groups (aged 60 years and older) and its repeatability in this age group has never been investigated. It would be useful to know if the results of the CVS-Q, when used in a general clinical population of older adults, mirrors that reported in the original study of computer workers. Since the COVID-19 pandemic, the use of digital devices in this age cohort is increasing (Ofcom, 2020, 2021, 2022a, 2023) and therefore it would be logical to assume the level of DES in this age group is also increasing. However, little work has been done into how best to assess this and whether existing techniques for the assessment of DES are as applicable in this age group as they are for other age groups.

Test-retest repeatability is an important aspect of measurement reliability as it provides important information about the consistency of a test over time. If a test is not repeatable it may be unreliable and may not provide accurate or consistent results, furthermore good repeatability suggests better precision of a single measurement (Vaz *et al.*, 2013). Test-retest repeatability is particularly important in research and clinical settings where it is essential to ensure that the tests being used are consistent and reliable. High test-retest repeatability also enhances the validity of a test because it ensures the results are not being influenced by external factors, such as time of the day, the attitude of the participant or the person administering the test. Test-retest repeatability in older adults is especially important given that age can lead to changes in cognitive and physical functioning that may affect the reliability of tests and measurements (Bäckman *et al.*, 2000; Lövdén *et al.*, 2020). Assessing test-retest repeatability in older adults is an important consideration in research and clinical practice to ensure that tests and measurement are reliable and accurate. Despite the CVS-Q being widely used (as demonstrated in table 5.1 above) there is a paucity of research about its repeatability in older adults (or indeed in any age group) and as such this an area where further investigation would be beneficial.

The aim of this study is to investigate the use of the CVS-Q in an older population (aged 60 years and older) and to determine its test-retest repeatability in this age cohort.

5.2 Methods

The study received a favourable opinion from the Health and Life Sciences Research Ethics Committee at Aston University (#21007) and was conducted according to the tenets of the Declaration of Helsinki. Patients aged 60 years and older (who used a digital device for at least 1 hour daily) attending for routine eye examination in an optometric practice in Dublin, Ireland, were invited to participate. Participants were taken seriatim, and participation was voluntary. Before entering the study, each participant was required to provide their consent after reading the participant information and transparency statement.

Participants had all taken part in the study described in Chapter 4 and completed the CVS-Q on two separate occasions, the first during their eye examination visit, and the second a minimum of 14 days or a maximum of 21 days later. This time interval has been reported to be sufficient to allow for accurate test-retest reliability of health status instruments (Marx *et al.*, 2003). Age, gender, ethnic group and smoking status (whether the individual has smoked in the last month) were recorded at the time of first completion. Sample size calculation for repeatability studies can be difficult to determine (Mokkink *et al.*, 2023). While a larger sample size can help in the gathering of high-quality data, for repeatability studies it is not always necessary and can result in greater cost to the study and increased inconvenience to the participant. Using tables from Mokkink *et al.* (2023), for a 95 % confidence interval a sample size of 200 was determined for repeatability in this study.

The study was carried out for 16 weeks between June and October 2022. Data were inputted into an Excel spreadsheet for analysis. As in the original report of the development of the CVS-Q (del Mar Seguí *et al.*, 2015) test-retest repeatability of the scores was determined using the intraclass correlation coefficient (ICC), and the concordance between the diagnoses was evaluated using Cohen's kappa (*k*), with their corresponding 95 % confidence intervals (95 % CI). The literature recommends an ICC >0.70 for discrimination between groups in research (Shrout and Fleiss, 1979; Koo and Li, 2016). Concordance, according to the kappa values, was classified as follows, <0.00 *poor*, 0.00 – 0.20 *slight*, 0.21 – 0.40 *fair*, 0.41 – 0.60 *moderate*, 0.61 – 0.80 *good* and >0.80 *almost perfect* (Landis and Koch, 1977). Coefficient of repeatability (RC), a calculation that relates to the 95 % limits of agreement proposed by Bland and Altman, was calculated between the two completions of the CVS-Q (Bland and Altman, 1999). Minimum clinically important difference (MCID), which determines how large should change in outcome be, to be clinically significant, was also determined from the mean difference and standard deviation of the results of the two completions of the CVS-Q at 95 % confidence level (Vaz *et al.*, 2013). Again as in the original report of the development of the CVS-Q, for each of the 16 different symptoms of the CVS-Q, the McNemar test was used to determine if the prevalence of each symptom varied between the two completions (del Mar Seguí *et al.*, 2015).

5.3 Results

Three hundred and eleven participants completed the CVS-Q on two occasions and were included in the final analysis; 198 were female (63.7 %) and 113 were male

(36.3 %). All participants were aged over 60 years, the median age of the respondents was 70.1 years, with a range of 60.0 to 93.9 years (IQR 64.6 - 78.6 years). The median number of hours of daily device use was 4 (IQR 2-5). Ethnicity of the respondents was almost exclusively white-Irish (99.4 %), with the remainder (0.6 %) being Asian-Irish. Regarding self-reported smoking status, 53 (17 %) had smoked in the last month and 258 (83 %) had not.

For the first completion of the CVS-Q (CVS-Q1), 196 (63 %) participants returned a score ≥6, the median score being 6 (IQR 4-8), with a range of 0 to 18; 129 females (65.1 %) had a CVS-Q1 score ≥6 and 67 males (59.3 %) had a CVS-Q1 score ≥6. For the second completion of the CVS-Q (CVS-Q2), 186 (60 %) respondents returned a score ≥6, the median score being 6 (IQR 4-7), with a range of 0 to 15; 124 females (62.6 %) had a CVS-Q2 score ≥6 and 62 males (54.9 %) had a CVS-Q2 score ≥6.

The median of the difference between CVS-Q1 and CVS-Q2 scores was 1 (IQR 1-2) with maximum difference in scores being 5 and the minimum being 0. Females had median difference of 1 (IQR 1-1) with maximum difference in scores being 5 and the minimum being 0. Males had median difference of 1 (IQR 1-2) with maximum difference in scores being 5 and the minimum being 0. Of the 53 self-reported smokers, a Mann-Whitney U test showed the median CVS-Q score in both completions was not significantly higher in smokers than non-smokers. Spearman's rank-order correlation coefficient showed a significant positive relationship between CVS-Q1 and CVS-Q2 scores (r_s= 0.8036, r_s^2=0.6457, P<0.00001) as can be seen in figure 5.1 below.

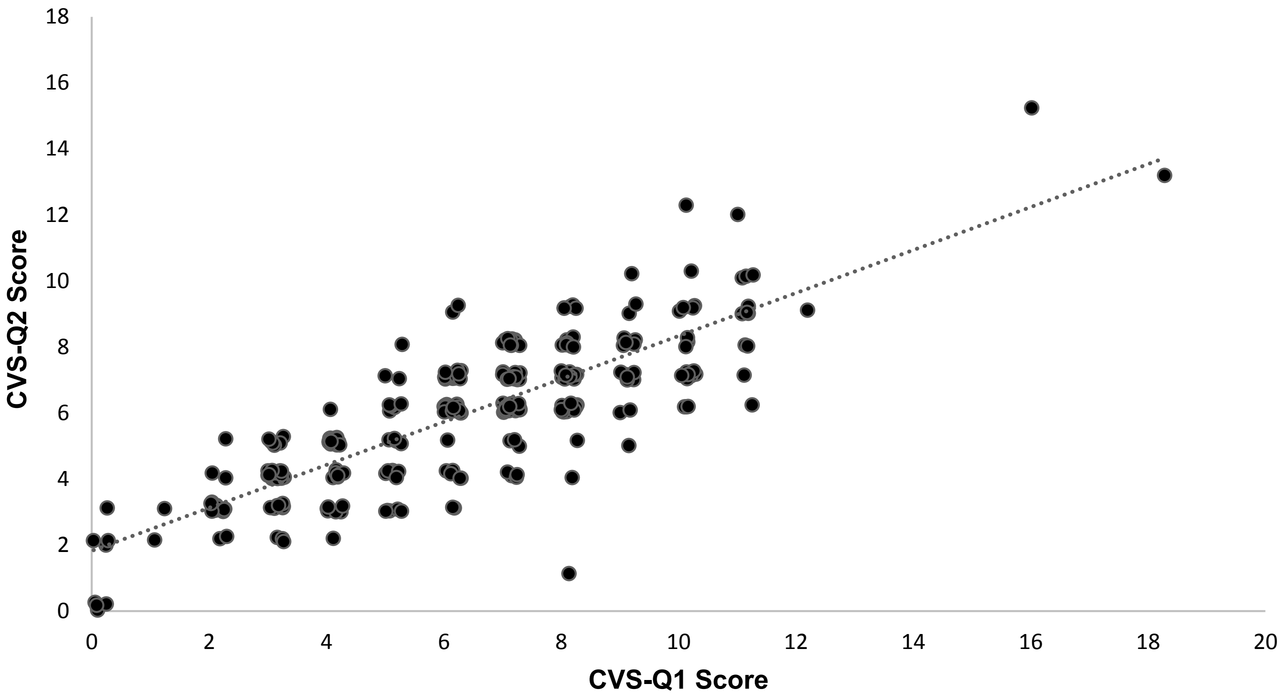

Figure 5.1: Correlation between CVS-Q1 and CVS-Q2 scores, r_s= 0.8036, r_s^2=0.6457, P<0.00001 (n=311). Data have been jittered to improve visibility of overlapping data points.

Figure 5.2 shows a Bland Altman plot of the mean CVS-Q score for each participant across the two CVS-Q completions versus the difference between the two scores (CVS-Q1 – CVS-Q2). The mean bias between completion 1 and completion 2 was 0.37. As the mean CVS-Q score increased, a small but significant increase in variability between the two completions was observed (r_s= 0.190, r_s^2=0.036, P=0.007).

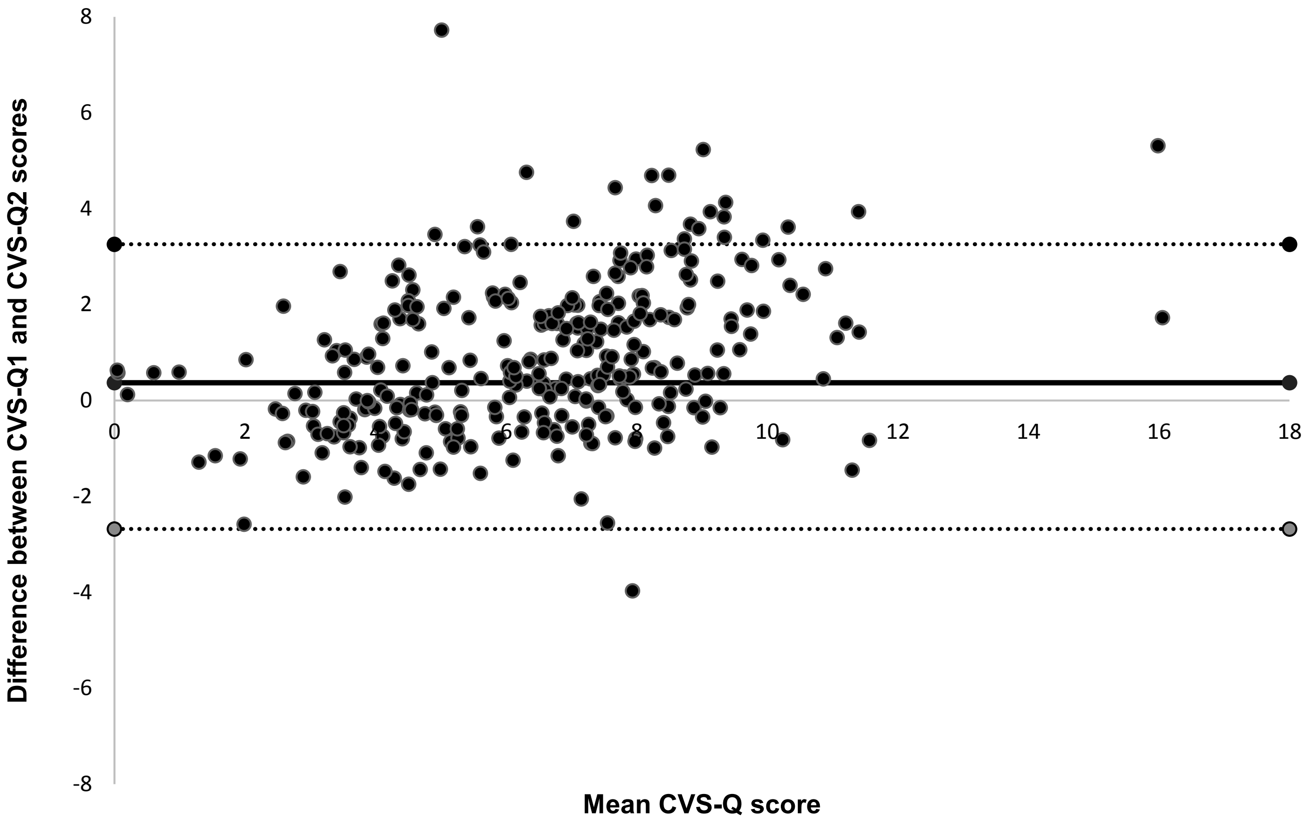

Figure 5.2: Bland Altman plot of the mean CVS-Q score for each participant across the two CVS-Q completions, versus the difference between the two scores (CVS-Q1 – CVS-Q2, n=311). Data have been jittered to improve visibility of overlapping data points. The solid black line indicates the mean bias, and the dotted lines indicate the 95 % confidence intervals.

Considering differences between the CVS-Q scores on completion 1 (CVS-Q1) and completion 2 (CVS-Q2), Spearman's rank-order correlation coefficient showed no significant relationship between age and this difference (r_s= -0.101, r_s^2=0.0102, *P*=0.075). The test-retest reliability of the diagnosis of DES for the two completions of the CVS-Q (i.e., score ≥6) was analysed by calculating Cohen's Kappa coefficient (*k*), with its corresponding 95 % confidence interval. The value was found to be 0.8108. Coefficient of repeatability (RC) was calculated at ± 2.7719. Minimum clinically important difference (MCID) was determined to be 1.96 (at 95 % confidence interval). The frequency of the symptoms selected differed between the CVS-Q1 and CVS-Q2, with 'feeling that vision is worsening' being the most selected in the former (72 %) and 'dryness' being the most selected in the latter (73.9 %). A full comparison of the different symptom frequency is shown in figure 5.3 below. Spearman's rank-order correlation showed a significant relationship between the symptoms selected on both completions (r_s=0.9748, r_s^2=0.9502, P<0.00001). As shown below in table 5.2 of the sixteen symptoms listed in the CVS-Q, McNemar test showed that only *eye redness (P*=0.0023*)* and *difficulty focusing for near vision (P*=0.0001*)* differed in prevalence between the two CVS-Q completions (*P* <0.05).

CVS-Q Symptom	P value
Increased sensitivity to light	0.926
Feeling that sight is worsening	0.9226
Feeling of a foreign body	0.9121
Eye pain	0.911
Itching	0.8481
Blurred vision	0.8041
Double vision	0.6056
Tearing	0.5329
Headache	0.5045
Burning	0.422
Dryness	0.3197
Coloured halos around objects	0.0961
Excessive blinking	0.0532
Heavy eyelids	0.0527
Eye redness	0.0023
Difficulty focusing for near vision	0.0001

Table 5.2: McNemar test *P* values for each of the 16 symptoms of the CVS-Q arranged in descending order, only ‘eye redness’ and ‘difficulty focusing for near vision’ have values <0.05.

Of the participants who completed the CVS-Q1 and had a score ≥6, the symptoms which had the highest sensitivity for predicting a positive result for DES were ‘dryness’ (86.7 %), ‘feeling that eyesight is worsening’ (86.25 %), ‘itching’ (83.13 %), ‘headache’ (79 %), ‘heavy eyelids’ (77.53 %) and ‘difficulty focusing for near vision’ (75.27 %). Of the participants who recorded a CVS-Q2 score ≥6 the symptoms which had the highest sensitivity for predicting a positive result for DES were ‘dryness’ (82.67 %), ‘feeling that eyesight is worsening’ (82.67 %), ‘itching’ (78.48

%), ‘headache’ (76.86 %), ‘heavy eyelids’ (72.37 %) and ‘difficulty focusing for near vision’ (63.05 %).

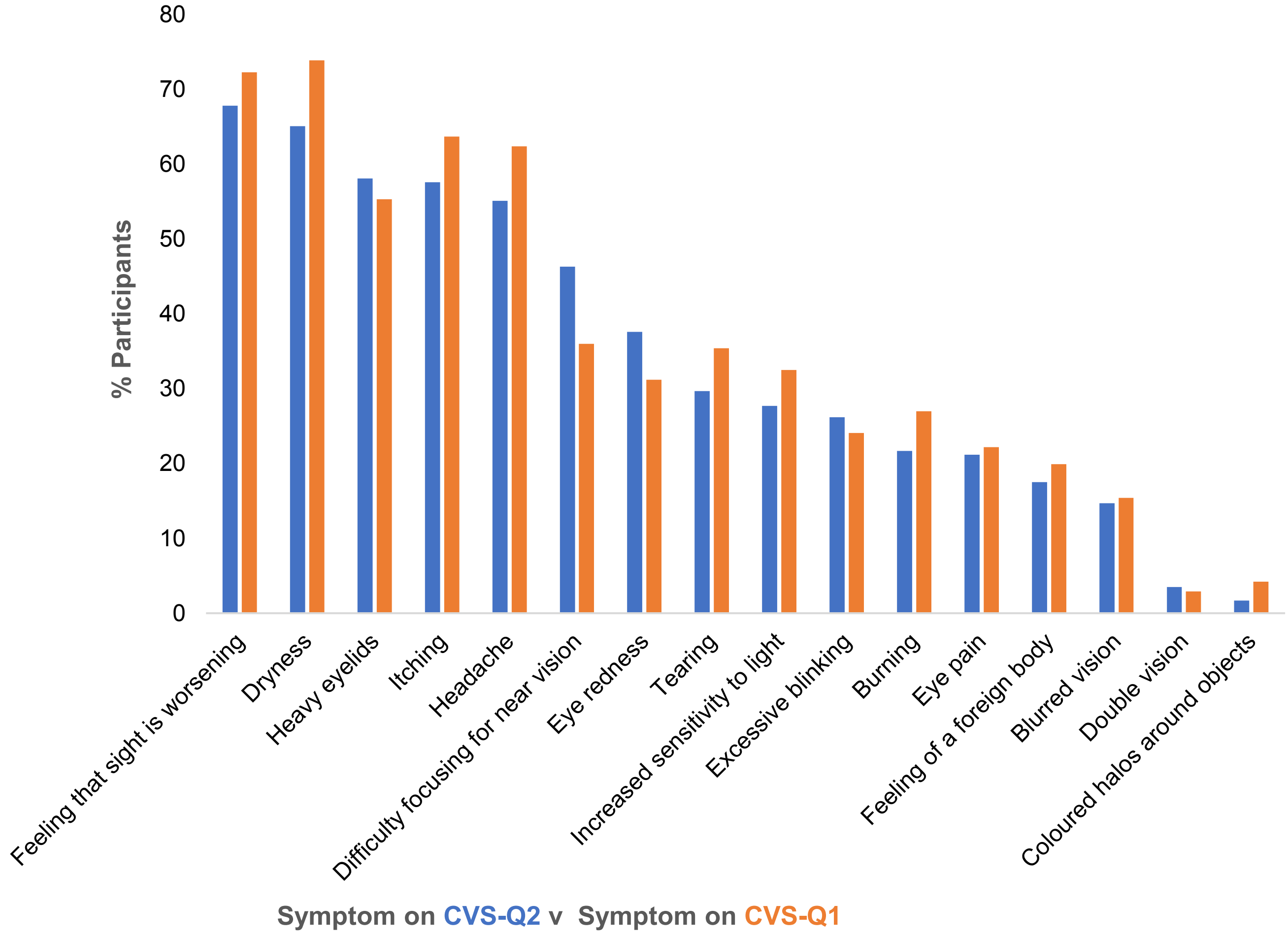

Figure 5.3: Comparison of the percentage of participants selecting each symptom when completing CVS-Q2 and CVS-Q1. A statistically significant difference was observed between the two completions for the symptoms ‘eye redness’ and ‘difficulty focusing for near vision’.

5.4 Discussion

This cross-sectional study on the repeatability of the CVS-Q in the detection and quantification of digital eye strain (DES) in older adults (aged 60 years and older) appears to be, at the time of writing, the first of its kind. Three hundred and eleven participants completed the CVS-Q on both occasions; considering that between 4 and 10 subjects per item must be taken for assessing questionnaire internal consistency, and as this instrument has 16 items, a sample size of 100 is sufficient (Terwee *et al.*, 2007; Bujang *et al.*, 2018) and this study, with 311 participants, exceeded that.

Of the 311 participants, 63% had a CVS-Q score ≥6 on first completion (CVS-Q1) while 60% had a score ≥6 on second completion (CVS-Q2). Findings from other studies into the incidence of DES have found a lesser prevalence of DES, such as Portello et al. (2012) where it was around 50 %, whereas others have found higher levels of between 64 % and 90 % (Hayes *et al.*, 2007; Yan *et al.*, 2008). Another survey of computer users showed that 'visual complaints' were reported by 75 % of computer users who work 6–9 hours per day in front of their screens (Mutti and Zadnik, 1996). A further survey of 419 computer users in India reported that 46.3 % of the users experienced two or more symptoms of DES either during or after computer work (Bhanderi *et al.*, 2008). Additionally, DES was also reported in over 50 % of call centre computer workers in Sao Paulo, Brazil (Sa *et al.*, 2012). Research since the COVID-19 pandemic has shown varying prevalence's of DES, such as 82.41 % by Zayed *et al*. (2021) and 62.4 % by Ahuja *et al.* (2021). These studies have used various criteria for the diagnoses of DES which could explain their differing results. It would be beneficial to the research in this area if all studies used a recognised and validated instrument for the diagnoses of DES, such as the validated CVS-Q, to make their results comparable.

There was a negative correlation between age and both completions of the CVS-Q which would suggest that age is not a good predictor of DES in this cohort. The results also demonstrate that older adults do not become unreliable when completing the CVS-Q. As part of this research programme, a study showed that hours of use of digital devices was a more accurate predictor of the incidence of DES in an older population (aged 60 years and older). There was no significant difference in the median CVS-Q scores between females and males in this cohort which is different to other studies of the prevalence of DES in working age adults (18 years and over) where a higher incidence of DES was found in females (Schaumberg *et al.*, 2003; Portello *et al.*, 2012; Rosenfield, 2016; Alabdulkader, 2021; Chawla *et al.*, 2021). A finding such as this, would indicate that gender may not be a good predictor of the incidence of DES in this age cohort. Smokers did not have a significantly higher CVS-Q score than non-smokers in either completion of the CVS-Q, which would suggest, that in this study, smoking was not a risk factor for DES.

While the frequency of symptoms selected by participants in this study differed between the two completions of the CVS-Q, 6 of the 16 were the most selected in both completions, furthermore, 5 of the possible 16 symptoms were the least commonly selected in both completions. When the CVS-Q scores from both completions are compared there is good correlation between them (r_s= 0.8036, r_s^2=0.6457, *P*<0.00001), which again would indicate that the CVS-Q is repeatable in this age cohort, moreover there is also good correlation between symptoms selected on both completions (r_s=0.9748, r_s^2=0.9502, *P*<0.00001). A good test-retest repeatability was observed for both scores and the positive diagnosis of DES (*k*= 0.8108, 95 % confidence interval). The *kappa* value of 0.8108 is classified as *substantial agreement* (Prinsen *et al.*, 2018) or *almost perfect* (Landis and Koch, 1977). Coefficient of repeatability (RC) was calculated at ± 2.7719 which indicates that 89.3 % of the results for both completions are within the 95 % limits of agreement proposed by Bland and Altman (Bland and Altman, 1999). Minimum clinically important difference (MCID) was calculated at 1.96 (at 95 % confidence interval) indicating that a change in score of ≥ 2 is clinically significant between the two completions; this MCID value could be used in future research into the proposed effectiveness of a treatment or intervention to reduce symptoms of DES in a 60 years and older symptomatic population. Of the 16 symptoms listed on the CVS-Q, only *eye redness* and *difficulty focusing for near vision* showed a significant difference in occurrence between the two completions, this may be explained by the fact the participants were presbyopic by virtue of their age and as such focusing, especially when prolonged, may be an issue in this age cohort (Millodot and Millodot, 1989) and that eye redness, a symptom of dry eye, does become more prevalent with age (Stapleton *et al.*, 2017).

Additionally, 6 of the 16 symptoms in CVS-Q1 and 5 of the 16 symptoms in CVS-Q2 showed sensitivities >70 % for overall positive results for DES (i.e., CVS-Q score ≥6), which means that it may be possible to reduce the number of questions required in the CVS-Q without having an impact on its accuracy which could increase the instruments use in general optometric practices as appointment times can in some case be restrictive (Pult and Wolffsohn (2019) developed a version of the OSDI questionnaire using 6 questions instead of 12 with no change in its accuracy, so it may be feasible to reduce the number of questions in the CVS-Q in a similar manner, however this would require further research and is beyond the scope of this current study).

As with any research this study has some shortcomings. There were more female responses than male and considering the link between dry eye and DES and that females are more likely to have dry eye (Craig, Nelson, *et al.*, 2017; Stapleton *et al.*, 2017), an equal gender balance would have been useful. Additionally, almost 100 % of the respondents were white-Irish which precluded any study into a link between DES and ethnicity in this cohort.

5.5 Conclusion

This study is the first of its kind to investigate the repeatability of the CVS-Q in the detection and quantification of DES in older adults. The sample size achieved of 311 participants was significant, with 63 % of participants having a CVS-Q ≥6 on first completion and 60 % having a CVS-Q ≥6 on second completion. The study found a negative correlation between age and both completions of the CVS-Q which suggests age is not a good predictor of DES in the age cohort. There was no significant difference in the CVS-Q scores between males and females and smoking was not found to be a risk factor for DES. The results also demonstrated that reliability of the CVS-Q is good in older adults. Good correlation was found between both completions of the CVS-Q and the study observed a good test-retest repeatability for both scores and the positive diagnosis of DES. It calculated a MCID value of approximately 2 which could be used in future research in DES to determine the effectiveness of an intervention to reduce symptoms. Overall, the study suggests that the CVS-Q is a reliable instrument for the diagnosis of DES in older adults. Furthermore, it would be beneficial to the research in this area if all studies used a recognised and validated instrument for the diagnosis of DES, such as the CVS-Q, to make their results comparable.

CHAPTER 6
CONCLUSION

6.1 General Conclusion

This programme of research was centred around the identification and management of digital eyestrain, with a focus on Ireland and the UK. It aimed to assess how optometrists in Ireland and the UK manage patients that attend their clinic with symptoms of digital eyestrain, to investigate optometric perceptions of the condition, to explore the occurrence of the condition in working age adults in Ireland and the UK and to investigate the occurrence of DES in an older population, which have been under-studied in the existing literature. The repeatability of the CVS-Q in older adults was examined to determine if it was an effective tool in this cohort. During the period of this programme of research, the COVID-19 pandemic occurred and this has resulted in more interest in the area of DES as a result of increased use and reliance on digital devices.

Prior to this programme of research, little was known as to the opinions and attitudes of optometrists to DES and how they approach it in practice. Study 1 (chapter 2) determined that optometrists in Ireland and the UK see DES as a significant problem that affects many of their patients and that they feel confident to offer advice to help manage the condition. An under estimation of the general occurrence of DES compared to reports in the scientific literature and a deficit of knowledge in some aspects of its management, such as the provision of occupational spectacles to reduce symptoms was found. Optometrists reported uncertainty about the issue of ‘blue light’ and DES, many (20 %) indicated that they were under informed about the issue, yet despite this, many prescribed ‘blue light’ filtering lenses for their patients. Areas where knowledge appears to be lacking could be addressed by the College of Optometrists (UK) and the AOI (Ireland) and the industries / manufacturers that supply into optometric practices. Optometrists may have little knowledge of the syndrome from their formal optometry education, therefore increasing the level of CPD on the topic could be useful in filling these gaps in knowledge and would provide the most up to date evidence-based information on the topic to optical professionals.

No previous projects had studied the occurrence of DES in working age adults in Ireland or the UK. Furthermore, no research had sought to investigate how those affected manage DES and the degree of problems caused by DES. The effect of working from home on DES was not known and given that this seems likely to continue, even post the COVID-19 pandemic, this is an area where research was needed. Based on a CVS-Q score of ≥6, the study found that 62.6 % of the 411 respondents were classified as having DES. In line with several previous studies, a clear association between greater hours of device use and the occurrence of DES was found. Those device users who worked from home were also more likely to suffer with symptoms of DES than those who did not. The study showed, that while many DES sufferers report significant symptoms, most do not seem to be significantly bothered by DES and only 8.1 % of participants reported their symptoms were severe enough to affect their work. The findings of this study are very relevant to the optometry profession, in that practitioners should be aware that a large number of their patients will be experiencing symptoms of DES when attending for their eye examination. Study 1 (chapter 2) found that optometrists estimated that 25 % of their patients will have DES whereas the figure in working age adults, at 62.6 %, is significantly higher. It may be valuable for employers to educate their employees, especially those who work from home, the best way to set up their working environment with advice on screen positioning, the importance of breaks, humidity and lighting. Optometrists could, in addition to eye care advice, give recommendations on workstation and environment set up to their patients who use devices regularly. It was found that participants who felt they had DES were in most cases (75 %) correct based on agreement with a CVS-Q score ≥6.

Whilst DES amongst working age adults had been investigated in numerous other studies in different countries, no study had specifically investigated its effects on older adults (≥60 years old). Since this age cohort is increasingly using digital devices, will be presbyopic and as age is a risk factor for ocular surface disorders, this was a significant gap in the research to address. In a cohort of older adults in Ireland, DES was found to be common with 51.6 % of the 401 participants having a CVS-Q score ≥6 and, in a similar finding to the cohort in study 2 (chapter 3), hours of use of devices rather than age were more closely correlated with a CVS-Q score ≥6. Whilst the CVS-Q was developed and evaluated using working age adults, it was found to be useful in this age group and has good repeatability. A minimum clinically important difference (MCID) score of 1.96 for the CVS-Q in older adults was determined and this value could be useful in further studies to determine if an intervention for DES is clinically significant. The study highlighted the potential for conducting practice-based research within a community optometry setting. Minimal disruption was caused to the practice while these aspects of the programme of research (studies 3 and 4) were being carried out; careful planning and the assistance of practice staff helped in this regard. Practice based research should be encouraged to help grow the evidence base supporting the profession and advice has been published by the College of Optometrists to assist practitioners in achieving this (Sheppard and Shah, 2021; Taylor *et al.*, 2022).

6.2 Evaluation of experimental work and limitations

For studies 1 and 2 efforts were made to distribute the surveys to as wide a population as possible. For the former, all local optometric committees in the UK were emailed a link to the survey, all members of the AOI were emailed a link to the survey and the College of Optometrists and AOP tweeted a link to it also. For study 2, a link to the survey was emailed to all staff in TU Dublin and Aston University, councils in the UK and Ireland were emailed about the survey and businesses local to the researcher's optometric practice were also informed of the survey. All studies achieved the required sample size from a *priori* calculation.

Study 1 was a self-selecting survey and as such it is likely that those practitioners with an interest in DES will be more likely to participate in it which could mean that results may not be representative of the wider optometry population. Of the 406 optometrists surveyed most, 189, worked in independent practices for future studies it may be beneficial to have an equal number of optometrists from different practice types to allow for a more representative sample.

By their nature, the participants for studies 3 and 4 were less diverse. The cohort consisted of consecutive adults aged 60 years and older presenting for an eye examination in a single optometric practice. As such, it was a convenience sample, although as this was the first study of its kind in older adults, an attempt to ensure a nationally representative population was not an aim of this study. Notably, the data are ‘real world’ and reflect those attending a primary care optometry practice. Future studies should look to draw participants from a wider and more diverse area to be more representative of the national population.

Studies 2, 3 and 4 could have benefitted from a more equal gender balance and a more diverse ethnic participation. For study 2 and 3 more information could have been gathered about the set up used by the participants when using their devices, such as screen positioning, room lighting and humidity. Attempts could have been made to assess actual screen use more accurately rather than relying on estimates provided by the participants. While many of these limitations were considered by the researchers, it was felt that requiring participants to meet these requirements could have made many aspects of the studies cumbersome and may have resulted in lower participation rates and given that adding more questions can reduce completion rates in surveys it was decided not to require this information (Chudoba, 2010)

6.3 Future work

This research project has determined the occurrence of DES in working age adults, and those aged over 60 in Ireland and the UK, however the occurrence and impact of DES in children is not known and therefore this is an area where future work could be considered. It has also calculated a MCID for older adults when using the CVS-Q, it would be useful to determine a MCID for other age groups using the CVS-Q.

While the CVS-Q is a useful instrument for the diagnosis of DES, there may be a way to shorten it and still maintain its accuracy as has been undertaken with other instruments (such as the OSDI (Pult and Wolffsohn, 2019)). A shorter questionnaire may be easier to use in busy practices where appointment times can restrict the addition of extra ‘tests’ for patients. It may also be possible to develop a new questionnaire for different age groups or device type user. For example, a questionnaire for DES in children will need easier to understand questions and will need to be shorter due to shorter attention spans.

Research in the field of DES typically relies on subjective estimates of device usage. As such, usage times may be inaccurate, so objective approaches to recording device use may be of value. There are wearable devices that have been used to monitor times outdoors and activities in myopia studies (Ostrin *et al.*, 2018) and such devices could be applied to research in the field of DES, although they would add significant additional cost and therefore may be more suited to university research setting rather than a primary optometric one.

6.4 Concluding statement

This programme of research investigated how optometrists perceive DES, how they manage their patients who present with DES symptoms and has found areas, such as occurrence rates and occupational spectacles, where this could be improved and where further education would be useful. DES was found to be a common problem in both working age and older adults, it determined the extent to which the problem bothered them and found that age alone is not an accurate predictor of DES whereas hours of device use is. The CVS-Q was found to be a useful instrument for the diagnosis of CVS-Q in both working age and older adults. Furthermore, the CVS-Q was found to be a repeatable instrument in older adults and that increasing age does not have a bearing on its accuracy. The research has determined a MCID value of 1.96 for the CVS-Q in older adults which could be useful in establishing if a course of action to reduce the symptoms of DES is effective in this age cohort.

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Appendices

Appendix A: Supporting documentation

Moore, P.A., Wolffsohn, J.S. and Sheppard, A.L. (2021) ‘Attitudes of optometrists in the UK and Ireland to Digital Eye Strain and approaches to assessment and management’, *Ophthalmic and Physiological Optics*, 41(6), pp. 1165–1175.

Appendix B: Ethics Committee Approval Form Study 1

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Memo

Life and Health Sciences Ethics Committee's Decision Letter

To: **Dr Amy Shepperd, Mr. Patrick Moore, Prof James Wolffsohn**

Cc: Charanjit Bhatti
Administrator, Life and Health Sciences Ethics Committee

From: Dr Rebecca Knibb
Chair, Life and Health Sciences Ethics Committee

Date 24/8/20

Subject: **Project #1652** Survey of attitudes of optometrists in Ireland and the UK towards Digital Eye Strain (DES), and their approaches to its diagnosis and management.

Thank you for your submission. The additional information for the above proposal has been considered by the Chair of the LHS Ethics Committee.

Please see below for details of the decision and the approved documents.

Reviewer's recommendation: Favourable opinion

Please see the tabled list below of approved documents:

Documentation	Version/s	Date	Approved
Response to reviewers' comments	1	23/7/20	✓
Participant information sheet	2	23/7/20	✓
Consent form	2	23/7/20	✓
Amendments to the ethics application	1	23/7/20	✓
Online survey	1	n/a	✓

After starting your research please notify the LHS Research Ethics Committee of any of the following:

Substantial amendments. Any amendment should be sent as a Word document, with the amendment highlighted. The amendment request must be accompanied by all amended documents, e.g. protocols, participant information sheets, consent forms etc. Please include a version number and amended date to the file name of any amended documentation (e.g. "Ethics Application #100 Protocol v2 amended 17/02/12.doc").

New Investigators

The end of the study

Appendix C: Ethics Committee Approval Form Study 2

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Memo

Life and Health Sciences Ethics Committee's Decision Letter

To:	**Amy Sheppard**
Cc:	Tim Batty
	Administrator, Life and Health Sciences Ethics Committee
From:	Dr Rebecca Knibb
	Chair, Life and Health Sciences Ethics Committee
Date	17/06/21
Subject:	**Project #1769 Digital Eye Strain in Computer / Digital Device Users in Ireland and the UK**

Thank you for your submission. The additional information for the above proposal has been considered by the Chair of the LHS Ethics Committee.

Please see below for details of the decision and the approved documents.

Reviewer's recommendation: Favourable opinion

Please see the tabled list below of approved documents:

Documentation	Version/s	Date	Approved
Response to reviewers' comments	1	8/6/21	✓
Risk assessment	1	11/4/21	✓
Participant information sheet	2	8/6/21	✓
Consent form	2	8/6/21	✓
Survey map	1	n/a	✓

After starting your research please notify the LHS Research Ethics Committee of any of the following:

Substantial amendments. Any amendment should be sent as a Word document, with the amendment highlighted. The amendment request must be accompanied by all amended documents, e.g. protocols, participant information sheets, consent forms etc. Please include a version number and amended date to the file name of any amended documentation (e.g. "Ethics Application #100 Protocol v2 amended 17/02/12.doc").

New Investigators

The end of the study

Appendix D: Ethics Committee Approval Form Study 3 & 4

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Memo

Health and Life Sciences Ethics Committee's Decision Letter

To: Dr Amy Sheppard, Mr Patrick Moore, Professor James Wolffsohn

Cc: Tim Batty

Administrator, Health and Life Sciences Ethics Committee

From: Dr Rebecca Knibb

Chair, Health and Life Sciences Ethics Committee

Date 9/6/22

Subject: **Project #HLS21007** Self-reported screen habits and associated symptoms in an older population.

Thank you for your submission. The additional information for the above proposal has been considered by the Chair of the HLS Ethics Committee.

Please see below for details of the decision and the approved documents.

Reviewer's recommendation: Favourable opinion

Please see the tabled list below of approved documents:

Documentation	Version/s	Date	Approved
Response to reviewers' comments	1	30/5/22	✓
Ethics application form	2	30/5/22	✓
Participant information sheet	2	30/5/22	✓
Consent form	2	30/5/22	✓
Risk assessment	1	15/2/22	✓
CVS-Q	n/a	n/a	✓
DEQ 5	n/a	n/a	✓

After starting your research please notify the HLS Research Ethics Committee of any of the following:

Substantial amendments. Any amendment should be sent as a Word document, with the amendment highlighted. The amendment request must be accompanied by all amended documents, e.g. protocols, participant information sheets, consent forms etc. Please include a version number and amended date to the file name of any amended documentation (e.g. "Ethics Application #100 Protocol v2 amended 17/02/12.doc").

Appendix E: Survey for Study 1

DIGITAL EYE STRAIN- SURVEY OF OPTOMETRISTS

About you

What type of practice setting do you mainly work in? *Required*

Large multiple
Small multiple
Independent
Public Hospital
Private Hospital
Educational/ academic
Other

If you selected Other, please specify:
In which country do you mainly work as an optometrist?

Ireland
UK

Number of years since you qualified as an optometrist *Required*

0 to 5 years
6-10 years
11-15 years
16-20 years
21-25 years
26 years or more

Digital Eye Strain and Patients

Digital eye strain (DES) amongst patients is an important concern for optometrists *Required*

Strongly agree
Agree
No opinion
Disagree
Strongly disagree

What do you understand by the term Digital Eye Strain (DES)? Please type a short explanation.
What percentage of patients attending your clinic do you believe are affected by Digital Eye Strain? Please type a number.
What would you consider to be the typical symptoms of DES? Please state these.

Digital Eye Strain and Patients 2

Digital Eye Strain may cause frequent and significant symptoms for sufferers *Required*

Strongly agree
Agree
No opinion
Disagree
Strongly disagree

Digital Eye Strain and Patients 3

I feel confident in discussing ocular symptoms related to computer use with patients and advising them on a range of management options *Required*

Strongly agree
Agree

No opinion
Disagree
Strongly disagree

Digital Eye Strain and Patients 4

How often do you ask patients about their computer use or digital device use during routine case history ? *Required*

Always
Frequently, i.e. more than half of the time
Around half of the time
Infrequently, i.e. less than half of the time
Never

Digital Eye Strain and Patients 5

In patients who you do question about their computer / digital device use, how often do you ask about the type of device used ? *Required*

Always
Frequently, i.e. more than half of the time
Around half of the time
Infrequently, i.e. less than half of the time
Never

Digital Eye Strain and Patients 6

In patients who you do question about their computer / digital device use, how often do you ask about the number of hours per day they use their device(s)? *Required*

Always
Frequently, i.e. more than half of the time
Around half of the time
Infrequently, i.e. less than half of the time
Never

Digital Eye Strain and Patients 7

In patients who you do question about their computer / digital device use, how often do you ask about the working distance of their device(s)? *Required*

Always
Frequently, i.e. more than half of the time
Around half of the time
Infrequently, i.e. less than half of the time
Never

Digital Eye Strain and Patients 8

In patients who you do question about their computer / digital device use, how often do you ask about the presence of symptoms associated with digital devices (i.e. headaches, dryness, eye strain / discomfort, blurred / distorted vision)? *Required*

Always
Frequently, i.e. more than half of the time
Around half of the time
Infrequently, i.e. less than half of the time
Never

Digital Eye Strain and the Eye Examination 1

How often do you modify the routine eye examination for patients who spend a lot of time using digital devices, or may be suffering from Digital Eye Strain ? *Required*

Always if symptoms reported with use
Frequently, i.e. more than half of the time
Around half of the time
Infrequently, i.e. less than half of the time
Never

Digital Eye Strain and the Eye Examination 2

If you do modify your routine, which of the following do you perform? (Please select all that apply) *Required*

Assessment of acuity at specific working distances of device(s) used
Cover test at working distance of device(s)
Fixation disparity at working distance of device(s)
Slit lamp examination of the ocular surface (e.g. TBUT, staining)
Look for other signs and symptoms of dry eye
Use of a dry eye questionnaire
Assessment of near point of convergence
Assessment of amplitude of accommodation
I never modify my routine
Other (please specify)

If you do use a dry eye questionnaire which one do you mostly use ?
If you selected Other, please specify:

Management of Digital Eye Strain 1

How important do you think it is to advise on taking regular breaks and looking into the distance for Digital Eye Strain? *Required*

Extremely important
Very important
Somewhat important
Not so important
Not at all important

Management of Digital Eye Strain 2

How important do you think it is to advise on the use of topical lubricants for Digital Eye Strain? *Required*

Extremely important
Very important
Somewhat important
Not so important
Not at all important

If you do advise the use of a topical lubricant which would you usually recommend ?

Management of Digital Eye Strain 3

How important do you think it is to advise on the office environment and workstation set up for Digital Eye Strain? *Required*

Extremely important
Very important
Somewhat important
Not so important
Not at all important

If you do advise on the office environment and work station set up for Digital Eye Strain what advice would you typically give ?

Management of Digital Eye Strain 4

How important do you think the use of specialist spectacle lenses for Digital Eye Strain is? *Required*

Extremely important
Very important
Somewhat important
Not so important
Not at all important
I don't know enough about them to give advice

If you do advise the use of specialist spectacle lenses for Digital Eye Strain which lens type(s) do you usually recommend ?

Management of Digital Eye Strain 5

How important do you think the use of short wavelength / blue blocking spectacle lenses is for Digital Eye Strain? *Required*

Extremely important
Very important
Somewhat important
Not so important
Not at all important
I don't know enough about them to give advice

If you do advise the use of short wavelength / blue blocking spectacle lenses is for Digital Eye Strain which lens type(s) do you usually recommend ?

Any other comments

If there are any further comments you would like to make on the topic of Digital Eye Strain and optometric management, please type these in the box. *Optional*

Final Page

That completes the survey. Many thanks for taking the time to complete it and please feel free to contact the research optometrist at moorepa@aston.ac.uk (Mr Patrick Moore) if you would like to receive information on the results of the survey.

Appendix F: Survey for Study 2

Digital Eye Strain in Computer / Digital Device Users In Ireland And The UK

About you

Which age band are you in? *Required*

18- 24 years
25- 29 years
30- 34 years
35- 39 years
40- 44 years
45- 49 years
50- 54 years
55- 59 years
60-64 years
65- 69 years
70 years and above

Gender: how do you identify? *Required*

Female
Male
Non-binary
Prefer not to say
Prefer to self-describe

If you selected self-describe, please enter your response in the box below:

What is your ethnic group ? *Required*

White- English, Welsh, Scottish, Northern Irish or British
White- Irish
White- Gypsy or Irish Traveller
White- any other White Background
Mixed/ Multiple- White and Black Caribbean
Mixed/ Multiple- White and Black African
Mixed/ Multiple- White and Asian
Any other Mixed or Multiple ethnic background
Asian/ Asian British / Irish- Indian
Asian/ Asian British / Irish- Pakistani
Asian/ Asian British / Irish- Bangladeshi
Asian/ Asian British / Irish- Chinese
Any other Asian background
Black- Irish
Black- British
Black- Caribbean
Any other Black, African or Caribbean background
Arab
Any other ethnic group
Prefer not to say
Prefer to self describe

If you selected self-describe, please enter your response in the box below:

Do you use computers (e.g. desktop / laptop) or other digital devices (e.g. tablet / smartphone / electronic ‘e’ reader) frequently as part of your work, i.e. on a daily basis? *Required*

Yes
No

Do you **currently** ‘work from home’ ? *Required*

No, I do not regularly work from home
I work from home for up to 15 hours per week
I work from home for between 16 and 30 hours per week
I work from home for more than 30 hours per week

Your use of computers / digital devices

Approximately how many hours would you spend using each of the following devices, on a typical working day?

Desktop computer
Laptop computer
Tablet / iPad
Smartphone
E reader

How has your usage of digital devices such as computers and smartphones changed since the start of the COVID-19 pandemic? *Required*

My usage has increased significantly since the start of the pandemic
My usage has increased slightly since the start of the pandemic
My usage has stayed the same as before the pandemic
My usage has decreased slightly since the start of the pandemic
My usage has decreased significantly since the start of the pandemic
Don’t know/ unsure

Your general eye comfort, dryness and wateriness

Eye discomfort: During a typical day in the last month, **how often** did your eyes feel discomfort? *Required*

Never
Rarely
Sometimes
Frequently
Constantly

When your eyes felt discomfort, **how intense was this feeling of discomfort** at the end of the day, within 2 hours of going to bed? Use the 0-5 scale to respond. *Required*

1.1 Never have it
1.2 Not at all intense

2
3
4
5- Very intense

Eye dryness: During a typical day in the past month, how often did your eyes feel dry? *Required*

1.3 Never
1.4 Rarely

2- Sometimes
3- Frequently
4- Constantly

When your eyes felt dry, **how intense was this feeling of dryness** at the end of the day, within 2 hours of going to bed? Use the 0-5 scale to respond. *Required*

1.5 Never have it
1.6 Not at all intense

2
3
4
5- Very intense

Watery eyes: During a typical day in the past month, **how often** did you eyes look or feel excessively watery? *Required*

1.7 Never
1.8 Rarely

2- Sometimes
3- Frequently
4- Constantly

Using computers / digital devices and your eyes

Considering the last month, how often did you experience pain or discomfort in your neck, shoulders or back **when using computers/ digital devices**? *Required*

Never
Rarely
Occasionally (approximately once per week)
Regularly (twice per week or more)
Very frequently (most days)

Considering the last month, how often did you experience symptoms **linked to your eyes** (e.g. dryness/ discomfort / visual problems / strain/ headache etc) **when using a computer or digital device**? *Required*

Never
Rarely
Occasionally (around once per week)
Regularly (twice a week or more)
Very frequently (most days)

On a scale of 1-10, how much do your symptoms bother you when using a computer / digital device?

1.9 Symptoms are barely noticeable and don't really affect me

2- Symptoms are very minor and an infrequent annoyance
3- Symptoms are minor and an occasional annoyance
4- Symptoms are more frequent but not problematic.
5- Symptoms are regular and somewhat annoying, but do not affect my work.
6- Symptoms are regular and more annoying but I manage to work as normal.
7- More problematic symptoms that are beginning to affect work.
8- Symptoms are often bad enough to affect work.
9- Struggling most of the time with severe symptoms- affecting work
10- Using computers / devices is almost impossible because of symptoms. Significantly affects ability to work.

Please identify which of the following eye / vision symptoms you experience when using a computer or digital device for work by first indicating the **Frequency** by clicking on 'Never', 'Occasionally' or 'Often / Always.' Then indicate the **Severity** by clicking on 'Not Applicable', 'Moderate' or 'Intense'.

	Frequency *Required*			Severity *Required*		
	Never	Occasionally	Often / Always	Not Applicable	Moderate	Intense
Burning						
Itching						
Feeling of a foreign body						
Tearing						
Excessive blinking						
Eye redness						
Eye pain						
Heavy eyelids						
Dryness						
Blurred vision						
Double vision						

Difficulty focussing for near vision						
Increased sensitivity to light						
Coloured halos around lights						
Feeling that vision is worsening						
Headache						

Which of the following do you do (or have tried) to relieve symptoms associated with computer/ device usage? Tick all that apply. *Required*

Look away from the screen frequently
Take regular breaks away from the computer/ device
Use lubricating eye drops
Take medication for pain relief
Use specialised 'computer' spectacles
Use my regular spectacles
Adjust screen settings, e.g. brightness, colour
Adjust room lighting/ window coverings
Adjust room environment e.g. temperature/ humidity/ air conditioning
I have not tried anything to relieve my symptoms
Other

If you selected Other, please specify:

Do you consider yourself to be affected by 'digital eye strain' (eye discomfort and vision problems when using digital screens for extended periods)? *Required*

Yes
No

Your eyecare

When did you last have an eye examination? *Required*

1 year ago or less
More than 1 year ago, up to 2 years
More than 2 years ago, up to 3 years
More than 3 years ago, up to 4 years
More than 4 years ago, up to 5 years
Over 5 years ago
Never
Not sure/ can't remember

During an eye examination, would you expect your optometrist (optician) to provide advice on managing eye / vision symptoms that can occur with computer / digital device use? *Required*

Yes

No
Don’t know / not sure

Do you currently use prescription spectacles or contact lenses when you are working on a computer or other device? Tick all that apply *Required*

Please select between 1 and 4 answers.

Spectacles- single vision
Spectacles- bifocal or varifocals
Spectacles- ‘ready readers’ (off-the shelf)
Contact lenses
Alternate between spectacles and contact lenses
No, I do not use prescription spectacles or contact lenses

Are you happy for your anonymised answers to this questionnaire to be used in future studies of digital eye strain by researchers at Aston University ? *Required*

Yes
No

Would you be interested in hearing more about future research in the field of digital eye strain at Aston University? E.g. opportunities to take part in further studies- these may be online only or involve visiting the University Eye Clinic. *Required*

Yes
No

If you selected Yes, please enter your email address below, or email moorepa@aston.ac.uk Your email address will not be shared with any other groups/ organisations, and would be used for the sole purpose of informing you about opportunities for taking part in research

That completes the survey. Many thanks for taking the time to complete it and please feel free to contact the research optometrist at moorepa@aston.ac.uk (Mr Patrick Moore) if you would like to receive information on the results of the survey.

Appendix G: Survey for Study 3

Study 3 Survey CRF: Self-Reported screen habits and associated symptoms in an older population.

1. Patient Code
2. Age in months
3. Gender: Female; Male; Non-binary; Prefer not to say; Other
4. Ethnic Group
5. Do you use a digital device daily?
6. Have you smoked in the last month
7. Type of digital device used: Desktop; Laptop; Tablet; Smartphone; E reader
   Primary digital device used: Desktop; Laptop; Tablet; Smartphone; E reader
8. Number of hours using digital devices daily
9. Best corrected binocular distance acuity (LogMar)
10. Best corrected binocular near acuity (N notation)
    Near add used (0 to > +4.00D)
    Working distance to nearest 5 cm
11. Best correct binocular acuity for the primary digital device used (N notation)
    Add used for the primary digital device (0 to > +4.00D)
    Working distance for the primary digital device to nearest 5 cm
12. Type of vision correction used for general use: single vision; bifocal; PALs; occupational; ready readers; contact lenses; none
    Type of vision correction used for primary device: single vision; bifocal; PALs; occupational; ready-readers; contact lenses; none
13. Specific symptoms mentioned when using digital devices: muscle pain; dry eye symptoms; visual / eye strain; headaches; focusing problems; tired eyes; none; other (free text entry)
14. Does the participant think they have dry eyes?
15. DEQ-5 questionnaire
16. DEQ-5 result
17. CVS-Q
18. CVS-Q result

Appendix H: Survey for Study 4

Study 4: Repeatability of the CVS-Q in the detection and quantification of digital eye strain in older adults.

1. CVS-Q first completion (CVS-Q1)
2. CVS-Q1 result
3. CVS-Q second completion (CVS-Q2)
4. CVS-Q2 result
5. Do CVS-Q1 and CVS-Q2 results agree?
6. Did this participant get a new optical correction for use with digital devices between completing CVS-Q1 and CVS-Q2?
7. If 'yes', what type of correction was prescribed?

Appendix I: DEQ-5

DEQ 5

1. Questions about EYE DISCOMFORT:

a. During a typical day in the past month, **how often** did your eyes feel discomfort?
0 Never
1 Rarely
2 Sometimes
3 Frequently
4 Constantly

b. When your eyes felt discomfort, **how intense was this feeling of discomfort** at the end of the day,
within two hours of going to bed?

Never have it	Not at all Intense				Very Intense
0	1	2	3	4	5

2. Questions about EYE DRYNESS:

a. During a typical day in the past month, **how often** did your eyes feel dry?
0 Never
1 Rarely
2 Sometimes
3 Frequently
4 Constantly

b. When your eyes felt dry, **how intense was this feeling of dryness** at the end of the day, within
two hours of going to bed?

Never have it	Not at all Intense				Very Intense
0	1	2	3	4	5

3. Question about WATERY EYES:

During a typical day in the past month, **how often** did your eyes look or feel excessively watery?
0 Never
1 Rarely
2 Sometimes
3 Frequently
4 Constantly
Score: 1a + 1b + 2a + 2b + 3 = Total

Appendix J: CVS-Q

COMPUTER VISION SYNDROME QUESTIONNAIRE (CVS-Q)

To be completed by worker

Indicate whether you experience any of the following symptoms during the time you use the computer at work. For each symptom, mark with an **X**:

a. First, the frequency, that is, how often the symptom occurs, considering that:

NEVER = the symptom does not occur at all

OCCASIONALLY = sporadic episodes or once a week

OFTEN OR ALWAYS = 2 or 3 times a week or almost every day

b. Second, the intensity of the symptom:

Remember: if you indicated NEVER for frequency, you should not mark anything for intensity.

	a. Frequency			**b.** Intensity	
	NEVER	OCCASIONALLY	OFTEN OR ALWAYS	MODERATE	INTENSE
1 Burning					
2 Itching					
3 Feeling of a foreign body					
4 Tearing					
5 Excessive blinking					
6 Eye redness					
7 Eye pain					
8 Heavy eyelids					
9 Dryness					
10 Blurred vision					
11 Double vision					
12 Difficulty focusing for near vision					
13 Increased sensitivity to light					
14 Coloured halos around objects					
15 Feeling that sight is worsening					
16 Headache					

To be completed by investigator

Calculation of **TOTAL SCORE** Apply the following expression:

$$\text{Score} = \sum_{i=1}^{16} (\text{frequency of symptom occurrence})_i \times (\text{intensity of symptom})_i$$

Considering that:

- Frequency:
  - Never=0
  - Occasionally=1
  - Often or always=2
- Intensity
  - Moderate=1
  - Intense=2

If the total score is ≥6 points, the worker is considered to suffer Computer Vision Syndrome