Healthy computer working

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> HEALTHY COMPUTER WORKING

Repetitive Strain Injuries (RSI), also known as Work-Related Upper Limb Disorders (WRULD), surged in the early years of this millennium due to computer work. In this thesis, the magnitude, causes and consequences of this phenomenon for the student population of the Faculty of Industrial Design Engineering (IDE) at the Delft University of Technology (TU Delft) are investigated and described. Longitudinal surveys on RSI amongst IDE students over a 15-year period (2000-2014) show the trend in prevalence and severity of the complaints. From the year 2000 to the present, a multidisciplinary RSI prevention group is active to create awareness, provide information and practical sessions. The organised prevention activities and their scientific basis are introduced and discussed. Furthermore, ideas for products and product-service systems, aimed at preventing or reducing RSI and based on medical insights and understanding of RSI risk factors, are presented. These ideas, developed in IDE master graduation projects and one from industry, are evaluated in user tests and physiological experiments with potential users.

The knowledge and insights gained in this thesis are not only valuable for design students to realise healthy computer working, but also for other educational and professional computer workers.

TUDelft

Marijke Dekker

> HEALTHY COMPUTER WORKING

Marijke Dekker

HEALTHY COMPUTER WORKING

HEALTHY COMPUTER WORKING

Work hard, play hard, and rest hard

HEALTHY COMPUTER WORKING

Dissertation

for the purpose of obtaining the degree of doctor
at Delft University of Technology
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CONTENTS

CHAPTER 1

INTRODUCTION

> INTRODUCTION

It was in the year 1998 that a student for the first time reported Repetitive Strain Injuries (RSI) to the student advisors of the Faculty of Industrial Design Engineering (IDE) at Delft University of Technology (TU Delft). Subsequently, in the academic years 1998/1999, 1999/2000 and 2000/2001, some 30 students followed, all having accrued a study delay. The Students' Health Service (in Dutch 'Studentengezondheidszorg' abbreviated SGZ), which maintained a registration system, received 38 IDE students with RSI complaints in the academic years 1999/2000 and 2000/2001, and issued a medical certificate for nine of them [1]. This statement indicating the student's reduced study capacity is supportive to discuss the possibilities for an adjusted study programme with the student advisor and financial compensation for student's RSI-related study delay by the university or–in severe cases–by the Central Bureau for Dutch Study Grants. The total time accumulated by the medical certificates of these nine IDE students was 24 months and the first student stopped studying due to RSI-related problems. In the following two academic years 2001/2002 and 2002/2003, the total time stated on the medical certificates issued to IDE students due to RSI complaints would even increase eightfold [1].

In response to the disturbing figures, a RSI prevention group for IDE students was established by the IDE Educational Director in October 2000. This RSI prevention group still exists after more than 20 years and is made up of a doctor of the Students' Health Service, a Health and Safety at Work and Environmental Advisor, a student member of the IDE Educational Management as well as a member of the IDE section Applied Ergonomics and Design, who is the author of this thesis. The main goal of this working group is to reduce RSI amongst students by preventing them as much as possible from getting (serious) complaints. This is realised through informing students about possible risk factors, training them to recognise RSI-related problems in an early stage and to respond quickly to incipient complaints. Additionally, the prevention group intends to reduce the fear and uncertainty–and therewith the chance of complaints getting worse–of students who experience more serious symptoms, by giving consistent information and a structure for what to do. Many activities in the early years focused on creating awareness by making the risk of RSI public by means of posters, brochures, an informative website on RSI and lectures for students and teachers. These staff members were informed on 'How to deal with students with RSI complaints', because of their contact with students and their involvement in the assessment of student work and the timing of delivery and exams. Sport and relaxation workshops (the so-called Sport, Pause and Relax Treat, abbreviated SPRT) have been organised for IDE students of all years and also for employees to create awareness for RSI and to emphasise the importance of relaxation and physical activity during intensive and long lasting computer use (see pages 10 and 11). Apart from disseminating RSI information, the working group concentrated on the reduction of risk factors within the IDE study, such as improving university workplaces and computer devices and the identification and distribution of peaks in the study load and computer use. Together with the Executive Board of the University, bulk discount programmes for office chairs and tables have been organised for the home workplace of students and staff members of all TU Delft faculties. Between these faculties, there was collaboration and knowledge exchange on RSI-related topics.

An important activity that has developed over the years and is still taking place is the incorporation of practical sessions related to RSI at several points in the IDE curriculum and providing students tools for prevention. In the first study year, following an introduction to RSI by the doctor of the Students' Health Service and a student RSI-experience expert, new IDE students receive instructions in groups from Cesar therapists on RSI prevention (see page 28). Students of higher years of studying meet these therapists while working with their laptop or computer during a computer practical. These instructions are more interactive in nature and students can ask for specific personal advice.

Although not exhaustive, the activities described above are an attempt to give an impression of the RSI prevention programme. The choice for and content of these particular activities over the years were based on the available scientific studies on RSI etiology, risk factors and successful interventions. These were at the time and still are, not conclusive. However, steps have been taken in knowledge development and the prevention group itself also gained experience. The link with these available scientific studies, the practical knowledge gained in the relatively strongly RSI-affected student community, and our scientific studies on the prevalence and seriousness of the RSI complaints within this population, are described in this thesis.

Table 1.1. Two definitions of RSI in literature

Definition 1	**Definition 2**
> RSI is a medical syndrome affecting the neck, upper back, shoulders, upper and lower arm, elbow, wrist or hand, or a combination of these areas. Its effects are restrictive or lead to participation problems. The syndrome is characterized by a disturbance in the balance between load and physical capacity, preceded by activities that involve repeated movements or prolonged periods spent with one or more of the relevant body parts in a fixed position. RSI is always caused by a combination of factors (Health Council, 2000 [2]).	> WRULD (or WRUED) comprise soft tissue disorders of the muscles, tendons, ligaments, joints, peripheral nerves, and supporting blood vessels (by Visser B, 2004 [3], based on Keller K, 1998 [4], and Sluiter JK, 2001 [5]).

Impression of the organised Sport, Pause and Relax Treat (SPRT) activities at the faculty.


S P R T
SPORT, PAUZE & RELAX TRAKTATIE
Dagprogramma di 12
Dagprogramma wo 13

Repetitive Strain Injuries (RSI) are a medical syndrome, affecting the muscles, tendons, nerves, joints and even the vascular and nervous system, as defined in Table 1.1. Throughout the last decades, not only RSI was used to indicate the related discomfort and pain symptoms in the arm, neck, shoulder and (upper) back region [2, 6] being subject of this thesis, but numerous other terms could be found in literature as well, like Cumulative Trauma Disorders (CTD, see Figure 1.1), Occupational Overuse Syndrome (OOS), and Work-Related Upper Extremity Disorders (WRUED) or Work-Related Upper Limb Disorders (WRULD), see Table 1.1. More recently, the focus has shifted towards plain designations just indicating the troubled physical area, such as Complaints of Arms, Neck and/or Shoulder (CANS). The rationale for this shift is that often no specific medical disorder or injury can be diagnosed, and the development of the complaints and the conditions in which they occur differ strongly.

Nevertheless, there is consensus on the nature of the complaints. These are mainly characterised by a feeling of pain, stiffness, tingling, numbness and loss of strength [6]. Because most RSI symptoms do not involve a diagnosable specific injury and are difficult to precisely localise in the body, these are described as non-specific. A smaller group of complaints also recognised as RSI are, however, specific. These include e.g. the tennis elbow and carpal tunnel syndrome (Figure 1.1). The distinction between non-specific and specific RSI complaints and the different types of specific RSI complaints are described in several studies [5, 8]. There is also consensus on the multifactorial nature of this syndrome's origin [9]. The most prominent risk factors mentioned in literature are of a physical nature, like repeated movements, static postures, awkward body positions, high forces, and high precision. However, also psychosocial risk factors such as stress and high job demands, as well as personality traits like overcommitment and perfectionism, have been associated with these problems [10, 11]. Furthermore, it was found that sustained physical activity in the form of movement, sport practising, exercise and/or fitness lead to a reduced risk [12, 13, 14]. The large variety of symptoms and risk factors suggests that there is not just one mechanism that explains the development of the complaints, but that several mechanisms may act simultaneously [15]. It is difficult to capture all the aforementioned aspects in a correct and complete name.

In this thesis both the terms RSI - as it is used e.g. in the Netherlands - and WRULD - as it is often called in British medical literature - will be used, also depending on the preferences of the journals in which the chapters of this thesis are published.

RSI occurs in several occupational groups involving repetitive movements and static postures such as hairdressers, racing drivers, plumbers, musicians, loaders/unloaders, packers, de-boners and poultry workers [6, 16, 17, 18]. However, the focus of this thesis is on computer work in which the repetitive component is above all clicking or tapping pointing devices (still most often the mouse), or - rapid - typing on the keyboard in a

CUMULATIVE TRAUMA DISORDERS IN OFFICE WORKERS

NEW JERSEY DEPARTMENT of HEALTH and SENIOR SERVICES

Public Employees Occupational Safety and Health Program

NEW JERSEY DEPARTMENT LABOR

Clifton R. Lacy, M.D.
Commissioner

James E. McGreevey
Governor

Albert G. Kroll
Commissioner

February, 2003

All sedentary workers...suffer from the itch, are a bad color, and in poor condition...for when the body is not kept moving the blood becomes tainted, its waste matter lodges in the skin, and the condition of the whole body deteriorates.

-Bernardino Ramazzini, 1700

Muscle aches and pains are common to many sedentary jobs...when the body is still, circulation is slowed and as a result fewer nutrients are delivered to the muscles, and fewer wastes are removed from the muscles, blood vessels and spinal discs.

- VDT Guidelines, N.J. Department of Health and Senior Services 2003

WHAT ARE CUMULATIVE TRAUMA DISORDERS?

Cumulative trauma disorders (CTDs) are injuries of the musculoskeletal and nervous systems that may be caused by repetitive tasks, forceful exertions, vibrations, mechanical compression (pressing against hard surfaces), or sustained or awkward positions. Cumulative trauma disorders are also called regional musculoskeletal disorders, repetitive motion disorders (RMDs), overuse syndromes, repetitive motion injuries, or repetitive strain injuries.

These painful and sometimes crippling disorders develop gradually over periods of weeks, months, or years. They include the following disorders which may be seen in office workers:

Carpal Tunnel Syndrome - a compression of the median nerve in the wrist that may be caused by swelling and irritation of tendons and tendon sheaths.

Tendinitis - an inflammation (swelling) or irritation of a tendon. It develops when the tendon is repeatedly tensed from overuse or unaccustomed use of the hand, wrist, arm or shoulder.

Tenosynovitis - an inflammation (swelling) or irritation of a tendon sheath associated with extreme flexion and extension of the wrist.

Low Back Disorders - these include pulled or strained muscles, ligaments, tendons, or ruptured disks. They may be caused by cumulative effects of faulty body mechanics, poor posture, and/or improper lifting techniques.

Synovitis - an inflammation (swelling) or irritation of a synovial lining (joint lining).

DeQuervain's Disease - a type of synovitis that involves the base of the thumb.

Bursitis - an inflammation (swelling) or irritation of the connective tissue surrounding a joint, usually of the shoulder.

Epicondylitis - elbow pain associated with extreme rotation of the forearm and bending of the wrist. The condition is also called tennis elbow or golfer's elbow.

Thoracic Outlet Syndrome - a compression of nerves and blood vessels between the first rib, clavicle (collar bone), and accompanying muscles as they leave the thorax (chest) and enter the shoulder.

Cervical Radiculopathy - a compression of the nerve roots in the neck.

Ulnar Nerve Entrapment - a compression of the ulnar nerve in the wrist.

Figure 1.1. The description of Cumulative Trauma Disorders (CTD) by the New Jersey Department of Health and Senior Services [7]

mainly static posture. In contrast to the aforementioned professional examples from the industrial sectors, the forces exerted during the repetitive movements with the hand and fingers during computer work are relatively low and the head and upper body barely move. Within this large group of computer workers the emphasis in this thesis is on university students. Consequently, it concerns young adults in a specific context coping with specific physical, psychosocial and personal risk factors. The scope of my thesis is the study environment and programme of students of the Faculty of IDE at the TU Delft. This concerns design students who are pushing boundaries while learning how to create meaningful societal and technological innovations through this 5-year university study[1]. The curriculum consists of theoretical courses and practical design assignments and combinations thereof.

The main questions of this thesis are:

- Why are students Industrial Design Engineering at risk?
- To what extent is this population at risk?
- What are promising prevention possibilities?

Intense screen work can also be a cause of eye and vision-related problems commonly known as Computer Vision Syndrome (CVS). Because of the often indicated relationship between visual complaints and RSI [19, 20, 21, 22, 23, 24] these complaints have been included in the studies of Chapters 2, 3 and 6.

> PLAUSIBLE ETIOLOGICAL MODELS

This thesis concerns the risks of students on developing RSI (WRULD), the related risk factors in the student context and promising prevention possibilities. In order to properly investigate these, some degree of understanding of the pathophysiological mechanisms contributing to the development of RSI symptoms is important. There are many studies on mechanisms leading to the large variety in symptoms of RSI, however these are not conclusive [25]. There also might not be just one mechanism explaining the complaints, but several mechanisms may act simultaneously or different mechanisms acting for different risk factors [15]. However, the author of this thesis describes three etiological models of which she thinks they represent plausible explanations.

1 An outline of the IDE Bachelor's and Master's programmes can respectively be found here: https://www.tudelft.nl/en/onderwijs/opleidingen/bachelors/industrieel-ontwerpen/bsc-industrial-design-engineering and here: https//www.tudelft.nl/en/ide/education/master-programmes

Impeded blood circulation

Reduced blood supply in the upper extremities is indicated as one of the causes of RSI [25, 26, 27]. Several physiological mechanisms were proposed as an explanation for the impaired blood flow. It is usually ascribed to static contractions of the muscles in neck and shoulders [28]. The assumption is that the mechanical pressure in the muscles reduces the diameter of the blood vessels. Consequently, the blood flow through the whole arm will be affected.

In other studies, the focus is on the low threshold muscle motor units of distal areas of the arm [29]. Because these are recruited early, do all the work and are the last to rest, this mechanism is associated with Cinderella and referred to as the Cinderella hypothesis [30]. Complaints may result from the lower force exertions common in computer work, because overloaded muscles can still occur in these circumstances while the subject is not aware of any overall feeling of muscle fatigue. In the aforementioned muscle related perspectives, the assumption is that inefficient blood flow to and in the muscles leads to anaerobe metabolism. Consequently, a deficit in substrates (including oxygen) and an accumulation of metabolites (mainly lactic acids) results. In prolonged contractions these acids cause discomfort and finally pain. Additionally, complaints can be intensified because a decrease in muscular microcirculation might lead to the sensitisation of pain receptors (nociceptors) in the muscle, meaning that low threshold stimuli can activate the pain system [31]. Armstrong et al. [32] argued that a reduction in muscle blood flow might lead to a cascade of responses in other body tissues (e.g., degeneration of the tendons and impaired circulation in the nerves), resulting in a range of complaints characteristic for RSI.

Brunnekreef, who extensively studied blood circulation in relation to RSI in later studies [33, 34], assessed local blood flow and local muscle oxygen consumption in forearm muscles of patients with RSI and healthy controls by using near-infrared spectroscopy (NIRS), a non-invasive technique based on oxygenated and deoxygenated changes of haemoglobin in the blood. At baseline, lower values for blood flow and oxygen consumption were observed in the affected forearm muscles of patients with RSI compared with the dominant arm of control participants. Immediately after hand grip exercises, patients with RSI demonstrated a lower oxygen consumption and a lower blood flow in the affected muscle of the forearm compared to the forearm muscles of healthy controls. A remarkable finding was that the values in the non-affected forearm in patients with RSI were similarly reduced. These findings suggested more systemic changes in the vasculature in patients with unilateral RSI. Furthermore, the oxygen consumption in patients with RSI was not correlated with the workload of the forearm as it was in healthy controls. The suggestion was made that the arteries in the affected arm of patients with RSI vasodilate less with exercise, resulting in a lower demand for oxygen and consequently blood flow in the affected arm of RSI than in healthy controls.

Local blood flow and oxygen uptake of the muscle tissue is regulated by the inner lining of the blood vessels, also called the vascular endothelium. A reduced blood flow to muscle tissue during exercise can therefore be caused by a reduced function of the endothelium. In another study of Brunnekreef [35] using non-invasive duplex ultrasound not only the brachial artery blood flow in the upper arm of patients with RSI and healthy controls was assessed, but also the endothelial function of the brachial artery with the method of flow-mediated dilation (FMD). The results showed a lower endothelial function as well as an impaired exercise-induced blood flow during handgrip exercise in patients with RSI. The relationship between these two findings suggest that the endothelial dysfunction might underlie the impaired vasculature in muscles of patients with RSI [36]. It was concluded that the endothelium-dependent vasodilatation seems to be diminished in the affected arm of patients with RSI compared to controls [35].

Brunnekreef states that the consequences of the attenuated blood flow and oxygen consumption – which is assumed to be closely related to blood flow – are a higher anaerobic metabolism leading to increased production of lactic acid and a diminished removal of waste products of the metabolic processes during exercise which may contribute to nociceptor stimulation and consequently fatigue and pain. The impaired blood flow responses may therefore contribute to the RSI symptoms that are evoked during repetitive movement tasks. However, it is unknown whether the found systemic vascular changes in people with RSI are a cause or a consequence of RSI. Also whether healthy individuals with a lower oxygen consumption, blood flow, or endothelial function are at risk to develop RSI is yet unknown [36].

Neuromotor noise theory

The neuromotor noise theory is described in a series of studies by Van Galen et al. [37, 38, 39]. In order to move and control the fingers, hand and arm, a certain degree of cocontraction of muscles through simultaneous tensioning of the agonists and antagonists (the benders and stretchers), is always present. This cocontraction becomes not only stronger by increased biomechanical factors like precision and speed but also by augmented psychological and cognitive factors such as anxiety, motivation, intrinsic arousal and cognitive task complexity [40]. The assumption is that when these factors increase, additional neuromotor noise is generated resulting in increased muscle activity. For example, when giving a presentation in front of a large audience, neuromotor noise may increase and the presenter will have a hard time directing the laser pointer on certain points on the slides [15]. During computer work, biomechanical, psychological and cognitive factors are present and influenced by the number and frequency of the repetitive movements, the precision demands in the tasks, the required speed in computer tasks, the complexity of the work, and the circumstances in which the work is carried out (sound, interruptions, cooperation, e.g.). Because the co-contraction makes the movement less efficient, more energy is required to achieve the same result, and the pressure in the muscles increases. Especially in tasks with a long duration, muscles will not have the time to recover and fatigue and pain will arise [41]. The assumption is that individuals with an enhanced tendency to react to stressors with heightened levels of muscular co-contraction are more prone to RSI complaints [40].

Bloemsaat [40] examined whether RSI-patients showed more permanent altered motor control, possibly because of their RSI condition, and found that patients had difficulty initiating movements and generated more force than healthy controls during a graphical aiming experiment with a pen on a tablet combined with an auditory memory task. This was considered as a demonstration of increased muscular cocontraction. In a second experiment of Bloemsaat [40] both groups had to regulate force by pressing a button with the index finger which corresponded to the movements of a square on a computer screen which had to stay within a certain target. The RSI-patients had more difficulty letting the applied force decrease in a controlled manner, which manifested itself in greater deviations around the target. The results of both these experiments strengthened the idea of altered aspects of motor control and central neural involvement in the development of RSI. Bloemsaat [40] emphasises in this perceptive that 'the core of the problem does not need to be at the place where it hurts' as is also acknowledged by physicians and therapists. He suggests that the focus of the intervention might consequently be aimed at restoring healthy behaviour and neural functioning, for example, by gradually training the individual to uncouple proximal and distal muscle activation. Potentially cognitive intervention may include, time management, preventing people from too much multi-tasking, stress coping and physical conditioning.

Pain Reception

In the previous sections, muscular, vascular and neural changes are discussed that may play a role in the etiology of RSI and also a role for personal factors are indicated. Van Eijsden-Besseling [16], former rehabilitation specialist, treated RSI patients for 15 years and studied risk factors evoking non-specific RSI and the factors playing an important role in the development of persisting complaints. She found that key triggers in the onset of the disease are a 'high task demanding work situation' interacting with psychological factors like perfectionism, while the course of the disease seems to be mainly influenced by the way a person copes with pain and experiences mental burden. Fear of physical movement because of irrational pain cognition - also called kinesiophobia [42] - seems to be counter effective and physical fitness could be an important factor in the prevention of the chronicity of the complaints. She concludes that patients with non-specific RSI need reassurance and when they score high on pain catastrophizing and perfectionism, a multi-disciplinary treatment including cognitive behavioural therapy by a psychologist is needed [16].

Psychological factors have also influence on muscle blood flow. It is well known that stress affects the RSI rates [11, 43]. When a person experiences high levels of stress, the activity of the sympathetic nervous system increases leading to a decrease in local muscle blood flow and lower washout of waste products [36]. As indicated earlier, the production of lactic acid stimulates nociceptors and causes discomfort and pain. On the other hand, pain in itself is also a stressor, since pain increases the secretion of stress hormones. These stress hormones (e.g. noradrenaline) stimulate the sympathetic nervous system and decrease the local muscle blood flow. So this process has a vicious circular character [25, 31].

Prolonged exposure to pain may ultimately lead to a lowering of the pain threshold through central sensitisation. This means the nervous system goes into a sustained state of high reactivity. This might explain the pain experience of RSI patients with long lasting severe complaints, which often shifts from local pain to more diffuse pain in the entire upper extremity region [36].

This central sensitisation can also result in a disproportionate pain experience, meaning that the patient experiences non-painful stimuli as painful and consequently disproportional limitations in abilities to move. Patients consciously or unconsciously associate pain with physical damage and experiences physical danger. Van Eijsden-Besseling [16] indicates the positive effects of graded exposure in vivo treatment, aiming to suppress the fear response. In this cognitive behaviour treatment, the patients' fear is activated, catastrophic thoughts are challenged and disproved. Based on photos of patients' fearful daily activities [44] an individual hierarchy of pain-related stimuli is made. Patients are encouraged to perform the least feared activity from the anxiety hierarchy as much as possible until the anxiety level has decreased. Then the next activity from the fear hierarchy is challenged. In a study [45] with patients with chronic non-specific WRULD and high pain-related anxiety receiving graded exposure in vivo, the level of pain catastrophizing and pain-related anxiety decreased significantly and there was improvement in perceived participation, autonomy and less pain disability. Van Eijsden-Besseling concludes in her thesis [16] that persons with non-specific WRULD and pain catastrophizing behaviour seem continuously aware of their complaints and do not have the ability to relax and participate in sports. The course of the disease then seems to follow the fear-avoidance model of Vlaeyen [46] as shown in Figure 1.2.

In the treatment of chronic WRULD, Van Eijsden-Besseling advises investigating the impediment by personality traits such as pain catastrophic behaviour and/or pain-related fear with the development of kinesiophobia. If patients score high on these factors, she recommends referral to a specialised centre for multidisciplinary therapy including the aforementioned cognitive behaviour therapy, graded exposure in vivo treatment and (specific) sports advice.

In the Netherlands, the Adelante centre of expertise in rehabilitation in Hoensbroek [49] is one of such multidisciplinary centres specialised in treatment of chronic pain like WRULD, including graded exposure in vivo. In the treatment by Adelante as communicated by senior researcher Albère Köke [50], pain is seen as a mental representation of our brains and an end result of activities in several brain areas, not only increased by (nociceptive) sensory information but also by beliefs, thoughts and emotions. The assumption is that due to central sensitisation in chronic WRULD patients, there are alterations in the central nervous system.

Figure 1.3 shows a representation of our pain system. The human receptors in the tissues respond to all kinds of stimuli that can pose a threat to the tissues. When the electrical charge reaches a critical level, a signal travels to the dorsal horn of the spinal cord. As soon as this warning message reaches the dorsal horn, electrically charged chemicals are released into the gaps (synapses) between the transmitting nerve fibers. When the electrical charge reaches a critical limit, a warning signal is sent to the brain (red triangles in Figure 1.3). Here, the message is processed by various brain areas. In the event that the brain concludes that danger is imminent and action must be taken, it produces pain. In this pain system, two 'switching stations' can be detected as indicated in Figure 1.3 by the two red circular marks located in the dorsal horn and the brainstem.

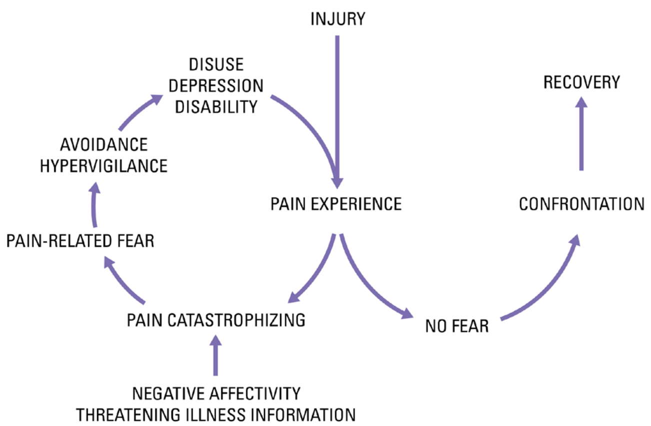

Figure 1.2. The 'fear'-avoidance model. Vlaeyen JW and Linton SJ, 2000 [46].
If pain, possibly caused by an injury, is interpreted as threatening (pain catastrophizing), pain-related fear evolves. This leads to avoidance behaviours, and hypervigilance [47] to bodily sensations followed by disability, disuse and depression. The latter will maintain the pain experiences thereby fuelling the vicious circle of increasing fear and avoidance. In non-catastrophizing patients, no pain-related fear and rapid confrontation with daily activities is likely to occur, leading to fast recovery. Pain catastrophizing is assumed to be also influenced by negative affectivity [48] and threatening illness information.

In the dorsal horn a selection is made whether and to what extent signals are amplified and sent to the brain. However, this system is influenced by beliefs, thoughts and emotions as processed in the brain (being therefore the second 'switching station'), affecting the descending pathways from the brain to the dorsal horn. These descending pathways (green triangles in Figure 1.3) can have both an inhibitory or facilitory effect on the chemical processes and operating neurotransmitters and receptors in the dorsal horn, and therewith on the pain sensation. For example, the inhibitory function of descending pathways decreases, and their facilitory function increases, by fear, hypervigilance and catastrophizing [51]. When the pain sensation is facilitated in this way for a long time, an (undesirable) 'learning effect' can arise in the brain, leading to chronic pain.

This central sensitisation may consequently account for pain sensations that are not in line with an injury and can arise without tissue damage, concern changing and enlarging pain locations, result from small movements or at skin touch, and even without any objective pain stimulus. The graded exposure in vivo aims at breaking the pain-danger relationship by making pain less threatening and improving functional ability by reducing the perceived harmfulness of activities. In line with this, the Adelante treatment [50] is based on influencing beliefs, thoughts, and emotions by 'training the brain'.

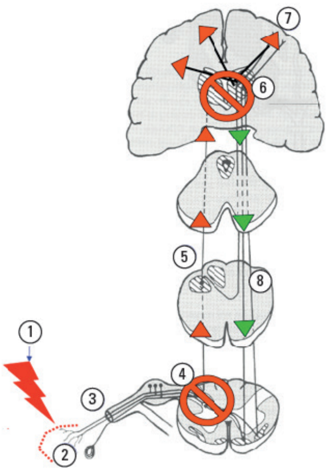

Figure 1.3. Pathways of pain reception in the peripheral and central nervous system. Köke AJA, 2017 [50]

1. pain trigger
2. stimulation nociceptors
3. transmission by nerve fibers
4. spinal cord: dorsal horn
5. ascending system
6. brainstem
7. several brain areas
8. descending system
🚫 *switching station*

> OUTLINE OF THE THESIS

Chapter 2 of this thesis is dedicated to the IDE RSI prevention programme and the longitudinal survey on RSI complaints amongst IDE students in the period 1999-2003 is introduced. In this chapter, a comparison of the Faculty of IDE with other faculties of Delft University of Technology is made concerning the percentage of students visiting the Students' Health Service (SGZ) with RSI complaints in the first years of the millennium. Relevant risk factors for these complaints are indicated. Chapter 3 shows the results of an extensive follow-up to this study. It concerns data of 2254 students gathered over 10 years (2004-2014). The trends are described and possible causes of increases of complaints related to societal changes are identified. The impact of the COVID pandemic and related changes in student's lives on RSI problems is also discussed.

The author of this thesis has been asked a few times to evaluate products from the industry for their effectiveness in terms of RSI prevention or symptom reduction. One example of such a study is presented and discussed in Chapter 4. As impaired blood flow is seen [25, 26, 27] as one of the main causes for RSI complaints, a product based on biofeedback, with the aim of restoring the blood flow in people with RSI complaints was evaluated. Both the suggested underlying physiological mechanism and the effect of the product on blood flow is investigated in a user research including participants with and without RSI. The results are presented and discussed.

Given the nature of the IDE education, which trains students to become product or product-service systems designers, students have developed possible successful interventions during their study projects and master theses. Two RSI preventive product ideas focusing on physical and cognitive break taking during computer work are presented in Chapter 5. One of the product ideas has been evaluated by a user group for the degree of induced cognitive relaxation and the results are discussed in this chapter. Also the product idea presented in Chapter 6 encourages the computer worker to take regular breaks in order to prevent RSI as well as Computer Vision Syndrome (CVS). The principle of this product idea is based on strong physiological needs. The desirability of the concept was investigated by a user group and discussed in this chapter.

Chapter 7 gives an overview of the main results from the different chapters. In Chapter 8, the interpretations of these results are given in relation to the research questions as formulated in this Introduction Chapter.

> IN SUMMARY

This Introduction chapter describes how the first students of the Faculty of Industrial Design Engineering (IDE) of Delft University of Technology (TU Delft) reported RSI complaints at the beginning of this century. Because the number and seriousness of the complaints increased, we started measuring them in the period 1999-2003 followed by a similar study on the longer period 2004-2014. Furthermore, a practical RSI prevention programme was set up, using the available and constantly developing scientific insights about the origination mechanisms and risk factors. In addition, this knowledge has contributed to design projects with regard to RSI prevention in graduation projects of IDE students and to the evaluation of RSI preventive products from the industry. Some of these projects and the theoretical basis are presented and discussed in the following chapters of this thesis. To this day, RSI is still present in society and also at the aforementioned faculty and the prevention programme still meets a need in a changing society. In order to be able to interpret the research in the following chapters, some important origination mechanisms are described in the last part of this chapter.

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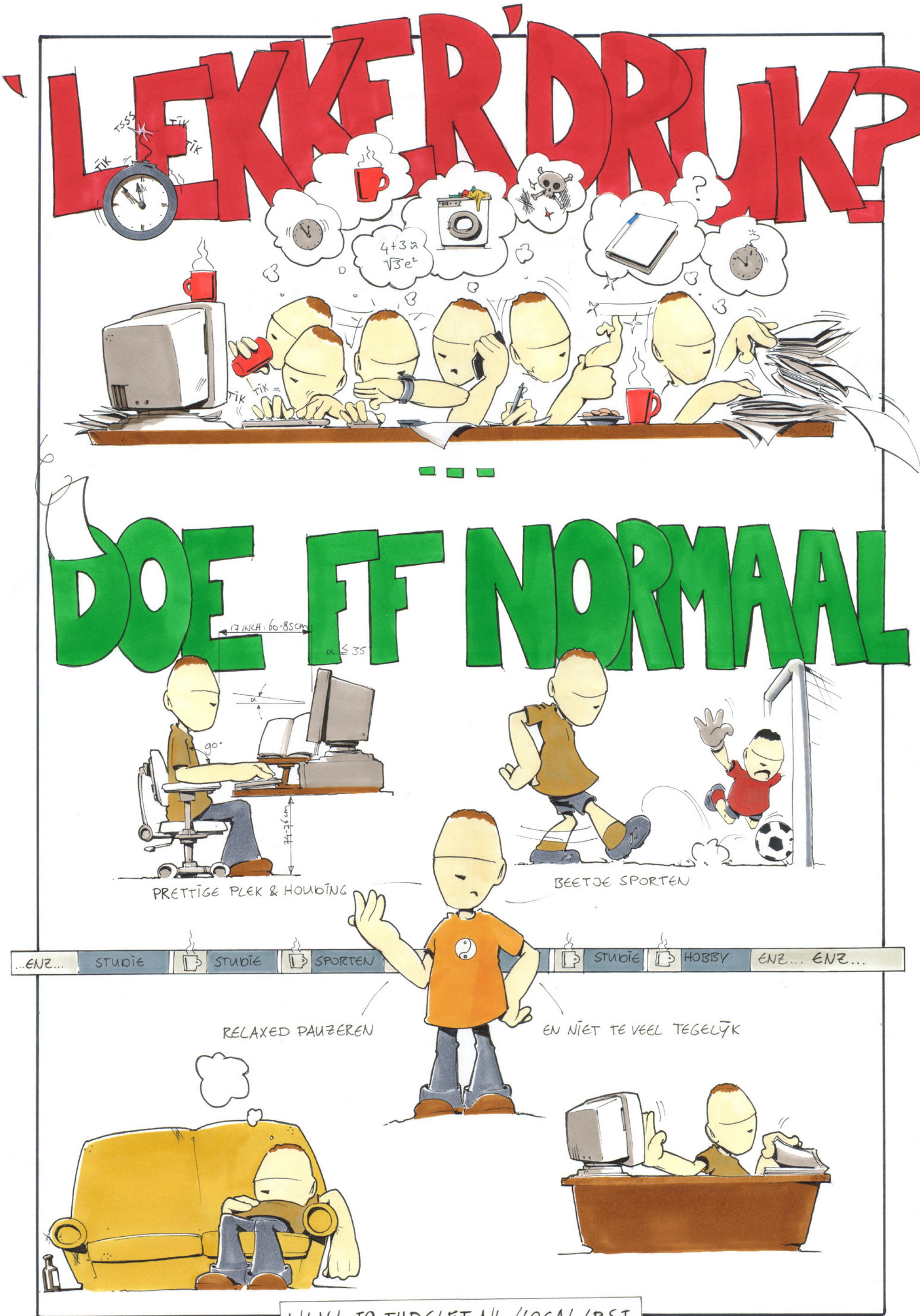

Poster made by Jan Selen in 2001 to make the RSI phenomenon public.

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CHAPTER 2

PREVENTION OF REPETITIVE STRAIN INJURIES (RSI) AT DELFT UNIVERSITY OF TECHNOLOGY

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Impression of the yearly organised RSI prevention sessions for first year students by Cesar therapists Jeroen Hutten and Cees Verhoeven

> ABSTRACT

RSI (especially non-specific RSI) is often classified as a syndrome because of the uncertainty of the cause and the variety of symptoms. Therefore, combined with a lack of injury evidence, RSI is a medically disputed phenomenon, not-withstanding the very serious human and financial consequences. Regrettably, there is still a great lack of knowledge about effective RSI prevention.

A multi-disciplinary RSI prevention group was set up at the Faculty of Industrial Design Engineering (IDE) at Delft University of Technology. This working group, supported by the Educational Director of that faculty, organised various prevention activities for students and – to a smaller extent – for universal employees on a yearly basis. The prevention programme will be presented.

In addition, surveys amongst IDE students were held to determine whether the group of students with RSI was increasing or diminishing and to establish the nature of the complaints. Although no direct relation between complaints and various prevention activities could be found in the presented surveys between 1999 and 2002, some tendencies will be reported.

> INTRODUCTION

The RSI phenomenon

Repetitive Strain Injury (RSI) is a medical syndrome affecting the neck, upper back, shoulders, arm, wrist or hand, or a combination of these areas. The symptoms – tingling, numbness, stiffness, pain, loss of strength, and loss of motor function – are preceded by activities that involve repeated movements of arms or hands, and require keeping some body parts in a static position. There is indication that precision demands and mental pressure contribute to the occurrence of complaints [1]. Most RSI cases are non-specific, this means no diagnosis can be made and there is no proof of any tissue damage.
The scientific discussion about the origination of RSI leads to very diverse insights and hypotheses. There are multiple possible mechanisms, but none of the hypotheses forms a complete explanation and is sufficiently supported by empirical data [1]. Furthermore, most RSI prevention is hardly supported by scientific knowledge.
With the increased use of the computer in the last decades, RSI is mostly associated with visual display unit (VDU) work. But also in industry, various professional groups such as hairdressers and poultry workers are dealing with repetitive movements. For all these workers, RSI is a health problem leading to – sometimes chronic – complaints, participation problems at work and home activities, and in a few cases even disability. Research based on self-reported data shows a wide range of prevalence rates for RSI (20-40%) through occupational sectors [2]. In 2001, the percentage of new disability pension entries caused by RSI through all occupational sectors in the Netherlands is 6% – which is 6000 people [3]. The industry has relatively the highest number of disability pension entries. Still, the absolute amount of people entering disability pension is highest in the administrative sector.

Another group at risk is the student population. The intensity of VDU work is high and the work is mentally demanding. Furthermore, workplaces at the university vary from course to course, and student's workplaces at home are intensively used. Therefore, their situation is different from professionals. Universities are obliged to observe most regulations of the Health and Safety at Work and Environment Act with regard to their students, although the legal position of students is slightly different.

The Delft University of Technology and specifically the Faculty of Industrial Design Engineering (IDE) of this Dutch university is an interesting research area in this perspective. The working hours per week – 40.9 hours – are the highest compared to other disciplines[1], computer use is high, and the work is mentally demanding because of the nature of designing.

1 Choice, centre higher education information for consumer and expert, Leiden, the Netherlands, 2004

RSI at Delft University of Technology

In 1998 the first students with RSI complaints due to VDU work approached the student advisors of their Delft University of Technology faculties to discuss the impact of these problems on their study progress. In the following academic years (1999-2003) a total of 274 students sought medical advice in relation to RSI complaints at the Students' Health Service (SGZ). IDE had the highest percentage of students consulting the SGZ (Figure 2.1) with 1.2 % (in comparison to 0.7 % of the Architecture students). In absolute numbers most new RSI cases came from the Faculty of Architecture with an average of 23 per year (in comparison to 18 cases at IDE). As can be noticed from Figure 2.1, the amount of new RSI students from the faculties IDE and Architecture consulting the SGZ because of RSI complaints seems to diminish gradually.

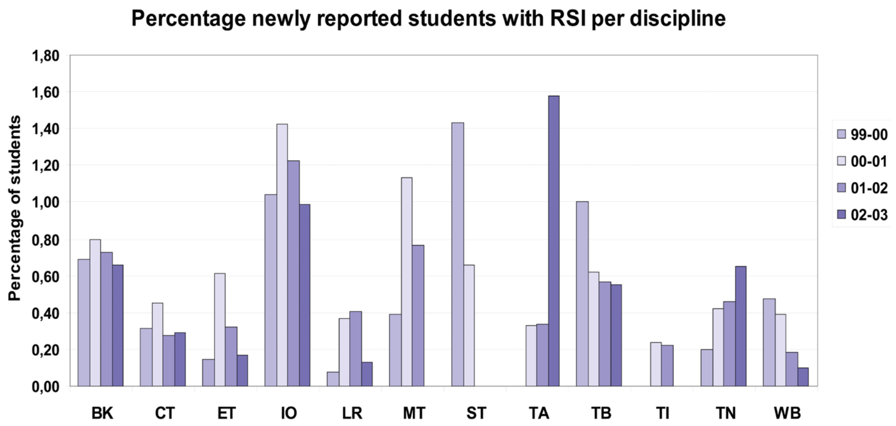


Figure 2.1. Percentage newly reported students with RSI per discipline at Delft University of Technology
BK = Architecture, CT = Civil Engineering, ET = Electrical Engineering, IO = Industrial Design Engineering, LR = Aerospace Engineering, MT = Marine Technology, ST = Sustainable Molecular Science & Technology, TA = Applied Earth Science, TB = Technology, Policy and Management, TI = Computer Science, TN = Applied Physics, WB = Applied Mathematics, WT = Mechanical Engineering

During these four years, about 43 % (118 students) reported such serious complaints, that after the physical check-up following a RSI protocol, the SGZ issued a medical statement. This paper indicated the reduced study load – for instance 100% reduction for some months or 50% for a period of one and a half year. The total time accumulated by the medical statements of these 118 students of the various Delft University of Technology faculties was 694 months (215 months by IDE and 302 by Architecture students). With this statement, the students had a stronger position in discussing the possibilities for a – temporarily – adjusted study programme with their student advisor, and a financial compensation for their RSI-related study delay. It should be noted that this study delay was in general longer than the time students were incapable of studying as indicated by the medical statements, because a hindrance of a week during the exam period could result in a study delay of a couple of months. The financial compensation for the accrued study delay, ranging from person to person from several months through to more than a year, was paid by the University or – in severe cases – by the Central Bureau for Dutch Study Grants.

Of course not all students with RSI complaints contacted the Students' Health Service – an unknown amount contacted their family doctor or other medical or alternative sources – so the total numbers and percentages of students with complaints are possibly much higher than indicated. But the more serious cases were probably all registered by the SGZ, because only they are authorised to issue the medical statements. A further 11 students dropped out of their studies due to RSI-related problems through these years (of which 3 IDE and 7 Architecture students). They stopped studying, started another study or restarted their original study after some time.

Economic consequences

Apart from the human consequences, there were also financial losses due to students' incapability to study in a regular pace and the cases of study termination. The government and Delft University of Technology together compensated with extra study grants for about 270.000 Euro. In addition, the university missed bonuses from the government – estimated at 80.000 Euro – because of the few students who dropped out of their studies and never got a Delft University of Technology university degree. The students incurred financial losses due to their RSI problems as well. The financial consequences of their extra study costs and delayed career, resulted in an average individual loss of 20.000 Euro.

RSI prevention at the Faculty of Industrial Design Engineering in the period 2000-2004

In response to the disturbing figures mentioned earlier, a working group on RSI prevention for IDE students was established by the Educational Director at the Faculty of Industrial Design Engineering in October 2000. The working group is made up of members of the Students' Health Service (SGZ), members of the Health and Safety at Work and Environment group of the Delft University of Technology, a student advisor and a student member of the Educational Management of IDE, as well a member of the section Applied Ergonomics and Design of the same faculty. The main goal of this working group is to reduce RSI amongst students by preventing them as much as possible from getting (serious) complaints. This will be actualised through informing students and – to a smaller extent – university employees about possible risk factors, training them to recognise RSI-related problems in an early stage and to react quickly towards beginning symptoms. Additionally the working group intents to reduce the fear and uncertainty – and therewith the chance of complaints getting worse – of students who experience more serious symptoms, by giving consistent information and a structure for what to do.

The creation of this prevention programme started in 2000. In science, there was still great uncertainty as to the risk factors and the effectiveness of prevention measures. Therefore, the programme was strongly based on the knowledge of the working group members such as the medical and practical experience of the SGZ director and the more theoretical and legal RSI knowledge of other working group members.

Many activities in the period 2000-2004 focused on making the risk of RSI public by means of posters, brochures, an informative website on RSI www.io.tudelft.nl/rsi, and lectures for students and teachers. Others concerned the incorporation of practical exercises in relation to RSI at several points in the IDE curriculum. In the first study year, following an introduction to RSI, new students get instructions on how to customise their workplace, practical exercises on working postures, and they get exercises for relaxation at the workplace. Third year students learn skills for time management and relaxation and are informed about their general health. Sport and relaxation workshops are organised for IDE students and employees of all years to create awareness for RSI and to provide RSI prevention tools.

Apart from disseminating RSI information and providing students tools for prevention, the working group concentrates on the reduction of risk factors within the IDE study, such as improving university workplaces and computer devices. Bulk discount programmes for office chairs and tables are organised for the home workplace as well. Lecturers are informed on 'How to deal with students with RSI complaints', because they are involved in the assessment of student work and the timing of delivery and exams. In the near future, the working group will examine the study programme to recognise peaks in the study load and in computer use. Suggestions will be made to the Educational Management for an improved distribution of these courses in future curricula. Furthermore, the working group set up an ongoing assessment by means of a biennial survey to monitor RSI amongst IDE students.

State-of-the-art knowledge on RSI risk factors and prevention

In these past 5 years that the IDE prevention programme was running, two inventories were made on behalf of the Dutch Ministry of Social Affairs and Labour as well as the Ministry of Health, Welfare and Sport about the state-of-the-art knowledge on RSI risk factors and effective prevention measures. In 2000, the Dutch Health Council [2] drew the following conclusion on risk factors from a literature study on RSI:

> *"Risk factors associated with RSI include excessive use of force, working in awkward positions, working continuously in the same position (static strain) and repeated movements. Psychosocial occupational factors do not themselves lead to RSI problems, but can exacerbate physical factors. Insufficient opportunities for recovery, psychological strain (extreme pressure of work, high levels of stress, high working tempo, mentally demanding work) and inadequate social support are probably significant."*

Moreover, it went on to state the following about prevention:

> *"At present, scarcely any data are available on the effectiveness of particular preventive policies – even those that are in wide spread use."*

and:

> *"Integrated preventive strategies that address all risk factors are likely to be most effective."*

About prevention of complaints becoming ever more serious it stated:

> *"It is very important that people consulting their GP or company doctor for early symptoms of RSI receive consistent advice. In early stages, particular emphasis should be placed on information and reassurance."*

Recently the two abovementioned Dutch Ministries commissioned a second study on neck and upper limb disorders (RSI) including a determination of which preventive measures for RSI have already proved effective and the state-of-the-art concerning RSI risk factors [4]. It concluded about risk factors:

> *"High frequent movements of the arm, certainly with force exertion, increase the risk on RSI drastically. The risk in VDU work seems to be increased in case of prolonged working."*

With regard to stress and workload, it stated that several recent studies produced reasonable evidence for stress and workload being risk factors for RSI. Limited evidence was found in personal risk factors, such as personality, perfectionism, sport practising and movement – a.o. it was found that physical activity in the form of sports, lead to a reduced risk and being strongly committed to the work, lead to an improved risk of RSI complaints. The study concluded about the effectivity of preventive measures that high quality research is still lacking. Only some tentative conclusions can be drawn that training of ergonomic skills[2] seems to diminish the incidence of RSI complaints. In this second study, only limited evidence was found on the effect of office tables and chairs with adjustable arm support to reduce complaints in arm, neck and shoulders. Although stress-related interventions such as relaxation training and time management courses could be effective, evidence is lacking. Additionally measures to diversify tasks and to provide time to recover might also contribute to prevention.

Evaluation of the IDE RSI prevention programme

Comparing the IDE RSI prevention programme with the recommendations of both previous studies, the conclusion can be drawn that they have a lot in common. For instance, the working group on RSI prevention also valued the importance of consistent

2 Ergonomic skills implied, amongst others, training to reduce neck rotations and extreme postures of the wrists and to improve the workplace and devices.

information and advice, resulting in easily accessible and unambiguous information sources. And the risk awareness of the combination of intense and prolonged VDU work together with psychological strain resulting from work pressure and mentally demanding tasks in the curriculum, was a central theme in the prevention programme. The emphasis was not only on the awareness but also on the creation of tools for students to reduce or avoid extreme workload and stress. Examples are the relaxation exercises and time management courses. Even suggestions on how to diversify tasks during work and to provide time for recovery after hard working are part of the prevention programme. The sport and relaxation promotion is based on the same conviction that change of body load is necessary, especially when working long hours with computers. Training of ergonomic skills and assistance on workplace optimisation at the university and at home are included already from the start of the programme.

> METHODS

Longitudinal survey

A longitudinal survey was set up by the working group to observe the trend, of the number of IDE students suffering from RSI and the seriousness of their complaints. Is the problem increasing, stabilising or reducing? In addition, an attempt will be made to gain more insight in the risk factors and to what extent the preventive measures taken by the working group had effect. These outcomes will help to improve the future prevention programme.

Surveys to monitor RSI amongst students at the Faculty of Industrial Design Engineering

Until today, two surveys were performed. From 2000 on, the students, as part of the first and third year RSI information sessions and instructions, manually filled in a short questionnaire on a voluntary basis. This resulted in the studies ‘Students and RSI 2000’ [5], abbreviated as ‘RSI2000’, and ‘Students and RSI 2002’ [6], abbreviated as ‘RSI2002’. A third study ‘RSI amongst students’, abbreviated as ‘RSI1999’ [7, 8], was already completed in 1999 and was initiated by the section Applied Ergonomics and Design of IDE. It was the first research project on RSI amongst IDE students. The students voluntarily filled in a digital questionnaire. The attention of all IDE students was attracted to this project by means of an announcement in the faculty newspaper and an electronic message that appeared on screen whenever a student logged into the faculty computers. The questionnaire of RSI1999 was more elaborate than the later two studies. Furthermore the questionnaire of RSI2002 was a bit more evolved than the RSI2000 one. Consequently, not all aspects of the three surveys can be compared.

Questionnaire RSI2002

The questionnaire of the most recent study RSI2002 is discussed here. It started with an introduction, outlining the goal and emphasising the anonymous nature of it. A general part included questions about age, gender, length and weight, mainly to check the representativeness of the respondent sample in relation to the IDE student population. The part in which the prevalence and seriousness of RSI was monitored, included questions relating to the occurrence of RSI-related complaints after VDU work, their location in the body, their frequency and duration. The questions about the duration and frequency of the complaints were included to estimate the severity of the complaints. It was considered that the complaints were more serious when lasting longer and occurring more frequently, and thus the seriousness was determined by the multiplication of the duration of the complaints and their reported frequency. An alternative estimation on the severity of the complaints was based on a checklist of daily activities such as tooth brushing, hand writing, carrying a bag etc [9]. The respondents had to indicate to what extent the complaints were limiting them in these daily activities. Another part of the questionnaire focused on possible risk factors and included, amongst others, a question about the amount of VDU hours per day (at home, at the university, or somewhere else). By means of an open question, the respondents were able to report the possible causes of their complaints, for instance courses in the curriculum or specific study facilities. A last part of the questionnaire focused on the effect of prevention activities. The first question was about prevention activities the students had come into contact with in the past. Nine options, such as RSI lectures, RSI website of IDE, RSI posters or the sessions on working posture were given. In answer to the second question, the perceived personal effect of these earlier activities was reported.

> RESULTS

One hundred fifty five students participated in RSI2002 (non response of 36%) and 290 students in RSI2000 (similar non response). The average age of the students in RSI2002 was 19.6 year and 20.5 year in RSI2000. In RSI2002, 52.9% was male and 47.1% female, in RSI2000 54.5% was male and 45.5% female. In the first study RSI1999, 181 students participated (non response of 88%) . The average age was 22.3[3] years; 64.6% was male and 35.4% female. The general sample information of the three studies, matched well with each other and with earlier measurements of Dutch males and females of age 20-30, which also included the IDE student population [10]. Therefore, the samples of these three studies are considered representative for the IDE student population. On some aspects the comparison could only be made between the last two surveys, because these were not investigated in RSI1999. Some results refer specifically to the

3 The higher mean age of RSI 1999 compared to the later studies is probably caused by the relative larger number of higher year students in RSI1999.

RSI2002 study, in particular the differences between years of study. Although the RSI2002 questionnaire was distributed as part of the first and third year RSI information sessions and instructions, the sample of this study also included 2nd, 4th, 5th, 6th and even some 7th year students, who had to redo the course or did not study on schedule (distribution: 1st 42%; 2nd 16%; 3rd 21%; 4th 13%; 5th, 6th and 7th 9%). All following tests were conducted with the Likelihood Ratio test.

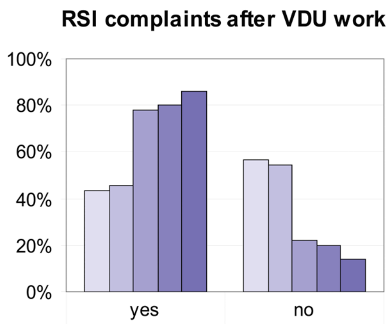
Prevalence of RSI complaints

Table 2.1 shows that comparable percentages of students with RSI complaints were found in RSI2002 and in RSI2000. In RSI1999, the reported amount of complaints was much higher. A significant effect was found for the complaints over the years.

Table 2.1. Comparison of the percentages of students experiencing complaints

	RSI2002	RSI2000	RSI1999
Complaints = yes	59%	61%	82%
χ^2 (2) = 29.32, $p < 0.001$			

The RSI2002 study shows a relatively large increase of complaints from the 2nd to the 3rd year (Figure 2.2). In general complaints occurred more often in higher years of study χ^2 (4) = 22.34, $p < 0.001$.



	yes	no
1st year	43%	57%
2nd year	46%	54%
3rd year	78%	22%
4th year	80%	20%
5th/6th/7th year	86%	14%

Figure 2.2. RSI-related complaints after VDU work per year of study (RSI2002).

The results relating to the body location of the complaints are quite similar through the three different studies. Most complaints occur in the neck, shoulders and wrist. Figure 2.3 illustrates the locations of the complaints in RSI2002 (in percentages of the total respondent group).

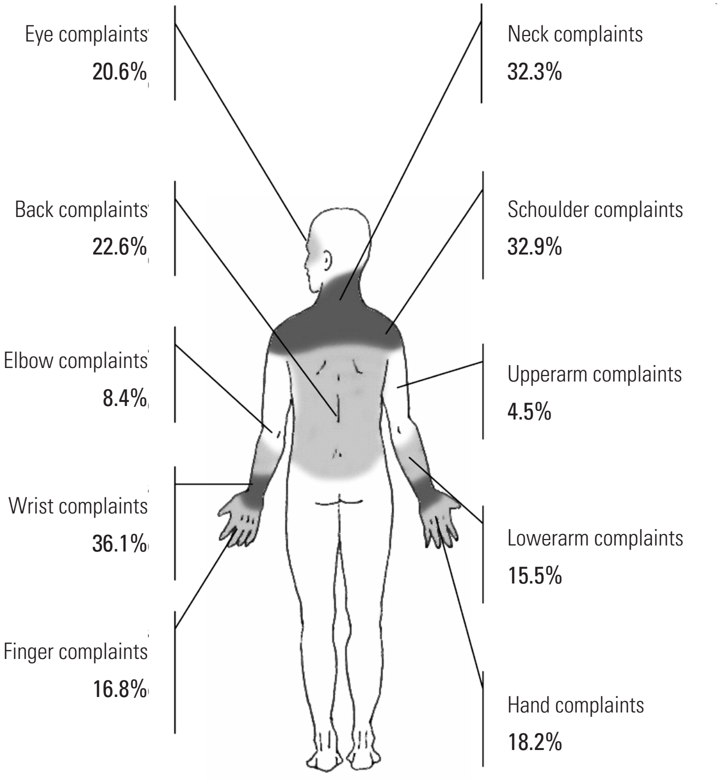


Figure 2.3. Locations of complaints (RSI2002)

Seriousness of RSI complaints

The frequency of the complaints (Table 2.2) show similar patterns over the three studies. Most of the students with RSI symptoms experienced complaints once a month or once a week, only few students experienced complaints every day. No significant effect was found for the frequency over the years.

Table 2.2. Comparison of the frequency of the complaints (within the group of respondents with complaints)

	RSI2002	RSI2000		RSI1999
Once a year	16%	13%	Sometimes	61%
Once a month	40%	45%		
Once a week	36%	35%	Often	28%
Every day	8%	7%	Very often	11%
$\mathcal{X}^2$ (4) = 3.14, p = 0.534				

The duration of the complaints (Table 2.3), show similar patterns as well over RSI2000 and RSI2002. For most of the respondents, the complaints last for less than 6 hours. Only a small group suffers from complaints that last longer than 24 hours. No significant effect was found for the duration over the years.

Table 2.3. Comparison of the duration of the complaints

	RSI2002		RSI2000
Less than 1 hour	58%	Less than 1 hour	53%
1-6 hours	27%	Half a day	29%
6-12 hours	4%	A day	12%
12-24 hours	4%	Twenty-four hours	4%
A couple of days	4%	More than twenty-four hours	2%
Continuous	1%		
χ^2 (4) = 7.13, p = 0.129			

The results of RSI2000 and RSI2002 related to the seriousness of the complaints, expressed in frequency x duration, are comparable (Table 2.4). A large amount of the complaints are not very severe (<100 hours per year). Less than a quarter of the complaints are more serious and last for 100-800 hours. A few complaints are very serious (>800 hours per year). No significant effect was found for the seriousness over the years.

Table 2.4. Comparison of the seriousness of the complaints

Number of hours of complaints per year	RSI2002	RSI2000
1-50 hours	55%	51%
50-100 hours	23%	20%
100-800 hours	14%	25%
800 hours and more	9%	4%

The seriousness of the complaints per year of study are compared in RSI2002. No significant effect was found for the seriousness over the years of study χ^2 (8) = 8.55, p = 0.382. The average score in the theoretical scaling of the severity of complaints expressed in limitation of daily activities was 1.14 (scale 1 to 5) in RSI2002. The highest score was 2 . Nineteen percent has some difficulty with hand writing and 2% quite a bit of difficulty; 15 % has some difficulty carrying a bag and 5% quite a bit; 12% has some difficulty holding a book and 4% quite a bit.

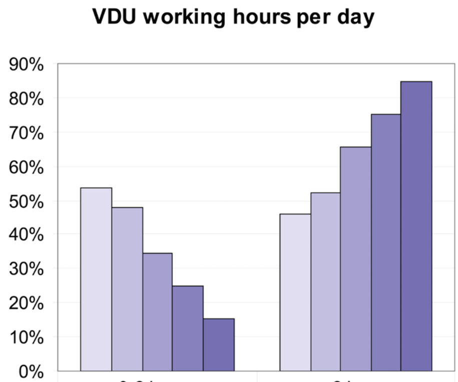
Possible risk factors

As can be seen in Table 2.5 the number of hours VDU work per day was higher in RSI2002 than in RSI2000 (more students worked 4-6 and more than 6 hours per day). A significant effect was found for the number of VDU hours per day over the years.

Table 2.5. Comparison of the number of VDU working hours per day

	RSI2002	RSI2000
More than 6 hours	9%	4%
4-6 hours	24%	10%
2-4 hours	26%	28%
1-2 hours	26%	39%
0-1 hours	16%	20%
χ^2 (4) = 20.74, $p < 0.001$		

The RSI2002 study shows that most students work both at home and at the university. The average amount of time spent on VDU work was 3.3 hours per day (1.8 hours at the home workplace and 1.3 hours at the university). Higher year students worked, on average, more hours behind the computer than lower year students χ^2 (4) = 11.60, $p < 0.05$ (Figure 2.4).



	0-2 hours	> 2 hours
1st year	54%	46%
2nd year	48%	52%
3rd year	34%	66%
4th year	25%	75%
5th, 6th & 7th year	15%	85%

Figure 2.4. VDU working hours per day per year of study (RSI2002)

In RSI2002 respondents most often reported the workplace as the most likely cause of their complaints. Other causes frequently reported were: the study burden, long working hours, and deadlines.

Perceived effect of prevention activities

On average, students had contact with three prevention activities in the past in RSI2002. The RSI lectures in the regular ergonomics courses, the first year sessions on working posture and relaxation exercises, the RSI brochure of the Delft University of Technology and the RSI website of IDE were the best consulted options. The answers to the open question about the perceived personal effect of these earlier activities indicated that a large part of the respondents changed their attitude (for instance, became more careful) and their intention (for instance, planned to reduce working hours) in relation to RSI prevention. 9% of the respondents even changed their behaviour (for instance, stopped working when experiencing complaints or made workplace improvements) in order to avoid RSI.

> DISCUSSION

In the time period 1999-2003, the Faculty of Industrial Design Engineering (IDE) had relatively the highest number of students experiencing RSI complaints when compared to the other disciplines of Delft University of Technology. This is hardly a surprise, because the educational programme of IDE contains many tasks that relate to risk factors for RSI as reported in literature. These risk factors are the frequent repetitive movements, required precision and static position of body parts, caused by the specific visual display unit (VDU) work, such as elaborate word processing, and the use of various graphic and 3D CAD programmes. The large number of working hours per week is an indication for a high study load at IDE, which is another RSI risk factor, especially in combination with intensive VDU work. Moreover, designing, creating new, non-existing products or environments, is – besides being attractive – also mentally demanding. It can become a 24 hours activity and the end of the job may be hard to determine.

The amount of VDU work per day has increased between 2000 and 2002. However, the results from the three surveys described in this chapter show a tendency that the occurrence of RSI complaints amongst students diminished or at least stabilised. The prevalence of RSI complaints at IDE is comparable (around 60%) in RSI2002 and in RSI2000. In 1999 the number of reported complaints was much higher (83%). This may indicate that a drastic reduction of RSI complaints between 1999 and 2000 occurred. However, it is more likely that the relative high number of higher year students in RSI1999 – who, on average experience more often complaints – contributes to this difference. Furthermore, the different ways of questionnaire distribution (see Methods paragraph) may be of influence.

The frequency and duration of the complaints, do not differ to a large extend over the years. Most of the students with RSI symptoms, experienced complaints once a month or once a week and only a few students experienced complaints every day. For most correspondents the complaints last for less than 6 hours. Only a small group suffers from complaints lasting more than a day. The seriousness, which was only calculated in RSI2000 and RSI2002, is very similar in these years as well. A large amount of the complaints are not very severe. Less than a quarter of the complaints are more serious and a few are very serious. In all three studies, complaints occur most frequently in the neck, shoulders and wrist.

From the RSI2002 survey can be concluded that students in higher years of study suffer most of RSI complaints. The number of RSI complaints in the years above the 3rd year is higher than in the 1st and 2nd years. However, no differences were found in the seriousness of the complaints between the study years. In general, students experiencing complaints have mainly 'somewhat difficulties' with daily activities.

The larger number of VDU working hours per day in higher years of study seems to be a feasible explanation for the increase of complaints in higher years, but has to be investigated in future surveys. It is very well possible that not only the amount of VDU hours but also underlying aspects, such as study load – a self-reported cause for complaints by the students – or being strongly committed to the work – responsibility towards other students or commissioners –, play a significant role in higher years.

Since 2000, an IDE working group on RSI prevention organises various prevention activities on a yearly basis. Does this prevention programme have any effect on the IDE students? It is hard to say to what extent the IDE prevention programme contributed to the reduction or stabilisation of the amount of RSI complaints. The fact that respondents reported in the last survey that they changed their behaviour or at least their attitude and intention looks very positive.

> ACKNOWLEDGEMENT

We would like to thank Renate De Bruin for the usage of her data RSI1999 and for her strong contribution to the surveys RSI2000 and RSI2002. And we would like to express our gratitude to Wim Van Donselaar, director of the SGZ, for the overview of numbers student visiting the Students' Health Service (SGZ) because of RSI complaints.

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CHAPTER 3

DEVELOPMENTS IN WORK-RELATED UPPER LIMB DISORDERS (WRULD) AMONGST DUTCH UNIVERSITY STUDENTS FROM 2004 TO 2014

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> ABSTRACT

Background Former studies on Work-related upper limb disorders (WRULD) within university education report substantial prevalence rates. In this study, developments in WRULD amongst students in the period 2004-2014 were investigated. Our findings can be a benchmark for future studies, in particular when there are major societal changes as in the case of the COVID-19 pandemic.

Objective Differences in time (academic year), how long students have been studying (year of studying), relations with computer time and societal changes were points of interest.

Methods 2254 students (average age 20.0 years) responded to a questionnaire on WRULD. Students experiencing complaints were further questioned about the severity of complaints and associated body locations.

Results The average percentage of students experiencing complaints was 57%. The highest prevalence rates and severity scores were found in the first and last recorded academic years. The neck, shoulder, back and wrist were most often indicated. The prevalence of complaints raised from the 1st (49%) to the 4th (75%) year of studying. Two seriousness measures showed highest scores in the 5th/6th/7th year of studying. Relations were found between both the prevalence and seriousness of complaints with reported computer time.

Conclusions After an initial decreasing trend from the academic year 2006/2007 to 2010/2011 there was an increase in WRULD amongst students from 2010/2011 to 2013/2014. Limiting financial and study time factors may have played a role. Structural attention for WRULD prevention and risk factors seems to be effective in reducing prevalence and severity of WRULD. This seems to be even more necessary due to recent COVID-related changes in the students' lives.

Keywords: RSI, MSD, prevalence, seriousness, COVID-19

> INTRODUCTION

Background

Work-related upper limb disorders (WRULD) in the occupational environment of The Netherlands is annually investigated by Van der Molen et al. [1, 2] of the Dutch Centre for Occupational Diseases based on the national notification and registration system. These studies show figures from computer-related occupations and manual labour in, e.g., transport, industry, and construction and indicate that musculoskeletal disorders are the second largest occupational illness - after psychological disorders – in The Netherlands. Within this musculoskeletal disorders category, the two most frequently reported occupational diseases are WRULD of the shoulder/upper arm (referring to non-specific WRULD of this region) and the tennis elbow (a specific form of WRULD). Since 2001 the reporting of occupational diseases related to the upper extremities has reduced as can be seen in Figures 3.1 and 3.2. Figure 3.1 shows the numbers reported WRULD per body region and Figure 3.2 shows the total numbers reported WRULD as percentage of all reported occupational diseases from 2000 till 2018 in the Netherlands. A possible explanation for this decline is the structural attention in The Netherlands for work-related causes and prevention measures in the work environment, in particular in computer work [1].

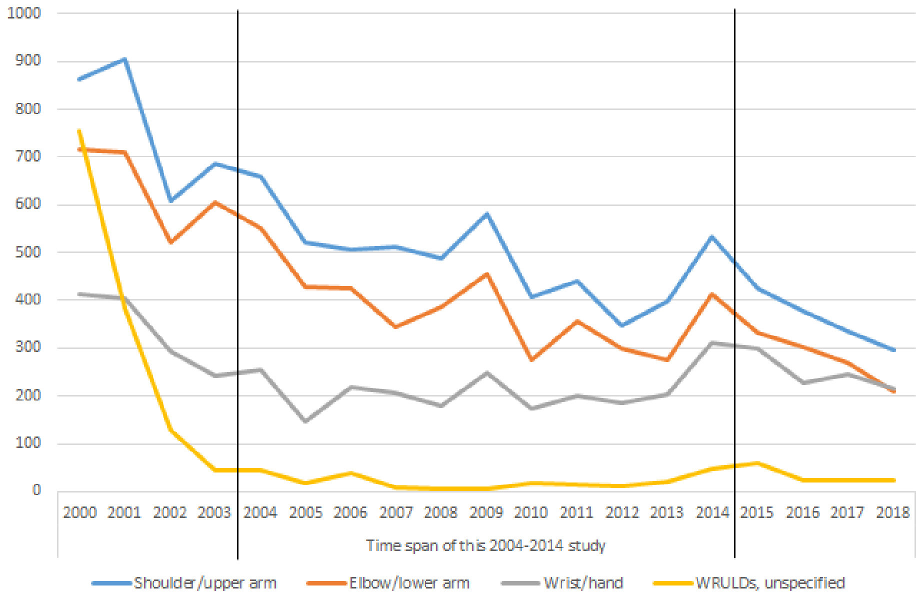

Figure 3.1. Number of reported WRULDs divided by body region from 2000 till 2018 in the Netherlands. Each line refers to multiple (specific and non-specific) forms of WRULD. Tennis elbow is included in the line 'elbow/ lower arm'. The lowest line refers to WRULD in unspecified regions. The black vertical lines indicate the time span of our 2004-2014 study. Source: national registry of Netherlands Center of Occupational Diseases 2019.

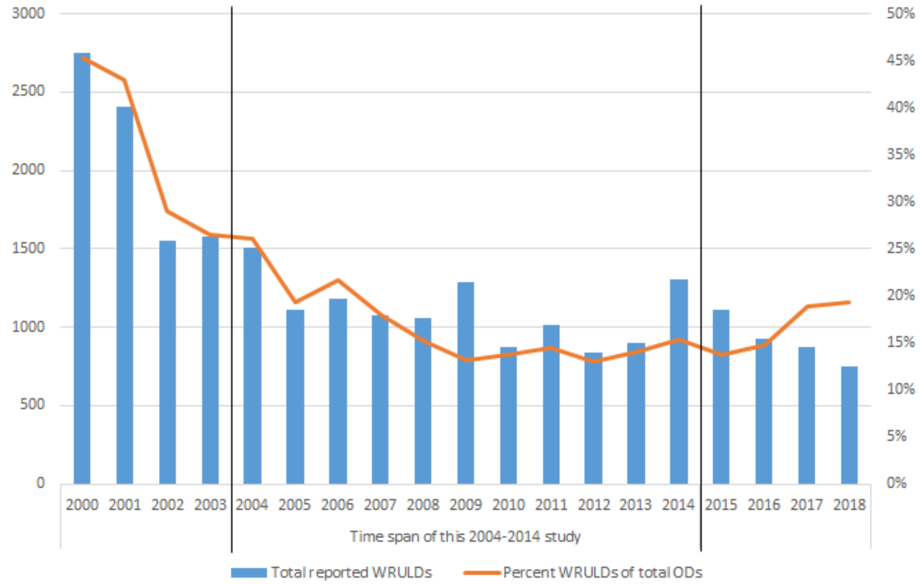

Figure 3.2. The total number of reported WRULDs (blue bars) and the percentage of these (red line) to the total number reported occupational diseases (ODs) from 2000 till 2018 in the Netherlands. The black vertical lines indicate the time span of our 2004-2014 study. Source: national registry of Netherlands Center of Occupational Diseases 2019.

However, a cross-sectional study on WRULD over such time span does not, as far as we know, exist for younger age groups. This seems strange because the use of personal computers, notebooks, and mobile phones has substantially increased in study, work activities, and leisure. This is a consequence of the digitalization and the more important role of the internet over the last 20 years. For their studies, digital reports and assignments, online assessments and examinations and online lectures have become more and more the standard. Recently, students had to change their life style drastically and abruptly due to the COVID-19 pandemic. Academic teaching became also in the Netherlands (almost) entirely virtual and on distance. Workload and restrictive governmental measures made students to be confined to their student homes with long working hours in front of their computer screen. Thus, the important questions are what the impact is of these developments on their health, and if these developments influenced the number and severity of WRULD complaints before they start their job. This is, of course, also a relevant question from an economical point of view. There are several studies that have addressed WRULD complaints of younger age groups over a shorter period of time. For example, the health effects of computer-related activities of secondary school students [3, 4, 5] and young adults [6-9] are explored. Dutch studies on WRULD within university education report WRULD prevalence of 76% [8] and 60% [9]. The cross-sectional study of Dekker & Festen-Hof [9] on WRULD among the student population of the Faculty of Industrial Design Engineering (IDE) at the Delft University of Technology from 1999 through 2003 showed that WRULD led to inconveniences and in some cases to absence, study delay and even dropping out of studies. In this paper it has also been shown that the related human and financial damage was substantial. Furthermore, risk factors have been indicated in this paper such as students' high work-load, long working hours, mentally demanding work and varying and not always adequate workplaces including the intensively used workplaces at home. The latter aspect has become particularly relevant in today's COVID-19 era where students work at home. Because the Dekker & Festen-Hof study [9] showed the impact of WRULD on students' health and productivity, the IDE Faculty supported monitoring studies on WRULD for a time period that stretches over 10 years, from 2004 till 2014.

Aims of the current study

In several studies [5, 10-12], an association was found between self-reported computer working hours and the prevalence of WRULD symptoms. In the former study among IDE students [9], the question was raised whether the higher percentage of students experiencing complaints in higher study years was related to the higher reported average number of computer hours per day in these years. Therefore, we investigated in the (2004-2014) study of this paper the relationship between the prevalence of WRULD symptoms and the time spent using a computer (whether for study, work or leisure). There are few studies available about the seriousness of WRULD symptoms in relation to computer working hours. However, the survey of Hakala et al. [13] examined the intensity of musculoskeletal pain and level of inconvenience to everyday life among adolescents in relation to their time spent using a computer and indicated that daily computer use of 2 hours or more is related to moderate/ severe computer-associated pain at the neck-shoulder, low back, head, eyes, hands, and fingers or wrists. The relationship between the seriousness of WRULD complaints and the reported average number of computer hours per day received also attention in the study of our paper. In summary, we analysed the data obtained from the students in the period 2004-2014 on the following measures,

> The prevalence, occurrence, duration and seriousness of WRULD complaints throughout the years 2004 - 2014,

> The prevalence, occurrence, duration and seriousness of WRULD complaints of students in different years of studying,

> The body locations associated with the complaints,

> The reported average number computer working hours per day spent by students throughout the academic years 2004 - 2014,

> The reported average number computer working hours per day spent by students of different years of studying,

> And the relation between WRULD prevalence and seriousness versus reported averaged number of computer working hours per day.

> METHODS

Procedure and Participants

To acquire measures on WRULD a survey was set out among IDE students of the Delft University of Technology comparable to the former survey among IDE students [9]. The research was set up and executed by the WRULD working group of IDE, a multidisciplinary group aiming to disseminate information on WRULD prevention and to reduce risk factors within the IDE study environment [9]. The WRULD working group is an initiative of the (Board of Educational of the) IDE faculty. Consequently, the monitoring of WRULD related health complaints among their students has been executed with approval of and within the policy of the university. The goal of the research and its anonymous nature was indicated at the start of the questionnaire. This way, all subjects were informed that data was acquired on group level and not on individual level. Students were asked by the researchers to participate and could refuse without reason giving.

The study of this paper was conducted in the academic years 2004/2005, 2006/2007, 2008/2009, 2010/2011 and 2013/2014 (in the figures respectively labelled with '04/'05, '06/'07, '08/'09, '10/'11, and '13/'14). The questionnaire was distributed in the 1st, 2nd, 3rd and 4th year of study after IDE examinations or WRULD information sessions. Students had to indicate how long they have been studying ('years of studying'). In the following analyses we only make use of this indication 'year of studying'. The sample of this study also includes students in their 5th, 6th and even 7th years of studying, who had to redo the course or did not study on schedule. It was made clear that the questionnaire was not intended for master students who didn't follow the IDE bachelor (such as international students) by verbal announcement during the passing round of the questionnaires. Therefore, the survey was administered in Dutch.

Measurement

Participants filled in the questionnaire on paper. Handwriting was chosen over online typing because of subjects' possible sensitiveness for computer-related WRULD. The questionnaire started with an introduction, outlining the goal and emphasising the anonymous nature of it. A general part included questions about age, gender, length and weight. The part in which the prevalence and seriousness of WRULD was monitored, included questions concerning the prevalence of WRULD-related complaints after computer work, their location in the body, and their occurrence and duration. It was considered that the complaints were more serious when lasting longer and occurring more frequently, and thus the seriousness was determined by the multiplication of the occurrence of the complaints and their duration, expressed in the total number of hours per year in which respondents experienced complaints and indicated with 'seriousness OxD'. An alternative estimation on the seriousness of the complaints, the 'seriousness LDA', was based on a checklist [14] of daily activities such as tooth brushing, hand writing, carrying a bag etc. The respondents had to indicate to what extent the complaints were limiting them in these daily activities. And there was a part of the questionnaire focusing on possible risk factors and included a question about respondents' number of computer hours per day.

Statistical analyses

The WRULD measures as previously indicated among IDE students of different years of studying were calculated and described over time. The Likelihood Ratio Test and one-way ANOVA were used to see if significant differences can be found between years of studying and between academic years, and to investigate relationships with daily computer working hours. In the following paragraph the total number of respondents (N) varies per analysis because of a small percentage missing values (e.g. forgotten/unwillingness to indicate year of studying, age etc) in the respondents' data.

> RESULTS

Two-thousand-two-hundred-and-fifty-four (2254) students participated in this survey (58.6% males/40.1% females/1.3% unknown). The average age was 20.0 years (minimum 16 years, maximum 46 years, SD 2.2). The response rate was estimated at 90-99% for students responding to the questionnaires distributed in the 1st year of study and 30-90% for those responding to the questionnaires distributed in higher years of study. In the Figures 3.3, 3.4, and 3.8 the width of the bars indicates the proportion of respondents numbers belonging to the specific category. There are different numbers of respondents per measure as presented in the following figures and tables. As can be seen, some measures concern the entire population researched and others only the group of students experiencing complaints. Moreover, missing answers of the respondents create also minor differences in sizes of the respondents groups per measure.

Prevalence of complaints in successive academic years

After a short introduction on WRULD, the respondents were asked whether they ever experienced physical complaints, such as pain, numbness, tingling or loss of strength, after working with a computer. In Figure 3.3, a mosaic graph presents the proportion of students experiencing WRULD as a function of academic year, including all years of studying (1 through 7 years). The percentages of complaints over the academic years are quite consistent. Percentages of students reporting complaints vary between 53% in academic year 2010/2011 and 61% in the academic years 2004/2005 and 2006/2007. There is a significant effect over the academic years ($\mathcal{X}^2$ (4, N= 2254) = 10.03, p = 0.04). The percentage of students experiencing complaints decreases from 2006/2007 till 2010/2011 and there is a slight increase to the last measured academic year 2013/2014 (58%). The average percentage of students experiencing complaints over all five academic years is 57%.

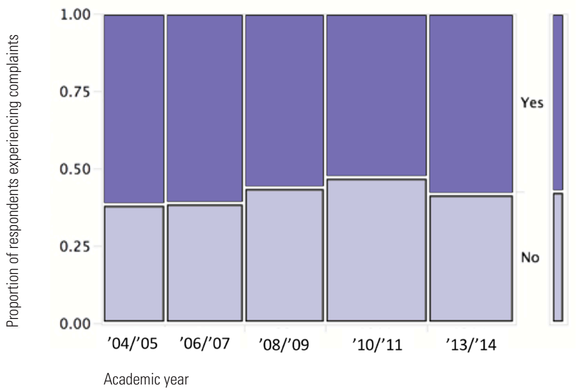

Figure 3.3. Proportions of students experiencing WRULD complaints as a function of the academic years, '04/'05 (n=346), '06/'07 (n=433), '08/'09 (n=444), '10/'11 (n=560), '13/'14 (n=471).

Prevalence of complaints per year of studying

The mosaic graph in Figure 3.4 presents the proportion of students experiencing WRULD after working with a computer as a function of years of studying, including all five academic years. Percentages of students reporting WRULD complaints vary between 49% in the 1st year of studying and 75% in the 4th year of studying. There is a significant effect over the years of studying (χ^2 (4, N = 2227) = 111.72, p < 0.0001). Relatively more students of higher years of studying experience complaints than students of the 1st year of studying. There is a slight decrease in the combined 5th/6th/7th year of studying (71%).

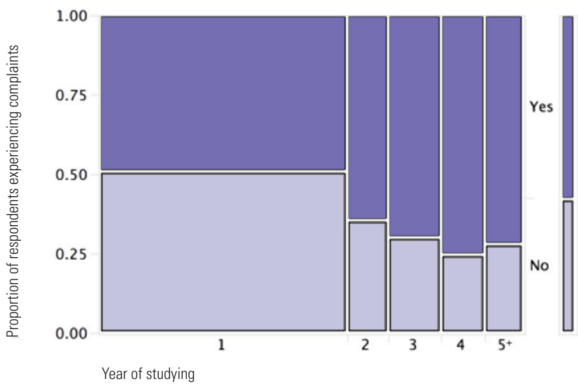

Figure 3.4. Proportions of students experiencing WRULD complaints as a function of their years of studying, 1 (n=1308), 2 (n=214), 3 (n=280), 4 (n=227), 5+ (n=198). The year of studying 5+ contains students who study in their 5th, 6th or 7th years. N = 2227

Occurrence of complaints in successive academic years

In this paragraph the data of students that reported complaints were analysed in relation to the occurrence of their complaints, obtained by a 4-alternative forced task: 'once a year', 'once a month', 'once a week', and 'once a day'. They only chose one level.
In Table 3.1, the percentages of complaints per academic year are shown as a function of level of occurrence. As can be seen in the right-most column, most students experienced complaints once a month (47%) or once a week (26%). There is a significant effect of the occurrence of complaints over the academic years. Complaints are experienced less

frequent in the academic year 2008/2009 compared to the academic years 2004/2005 and 2006/2007. More students experienced yearly (24%) and monthly (49%) complaints in the academic year 2008/2009 and less students suffered from weekly (21%) and daily (6%) complaints. In the last two academic years 2010/2011 and 2013/2014 however, there is an increasing percentage of students suffering from weekly (respectively 27% and 33%) and daily (respectively 11% and 15%) complaints and a decreasing percentage students experiencing yearly complaints (respectively 15% and 11%) and monthly complaints (respectively 47% and 42%).

Table 3.1. Occurrence of complaints in percentage of the group respondents with complaints within the successive academic years.

	2004/2005 n = 201	2006/2007 n = 251	2008/2009 n = 237	2010/2011 n = 285	2013/2014 n = 255	All N = 1229
Once a year	16%	20%	24%	15%	11%	17%
Once a month	45%	49%	49%	47%	42%	47%
Once a week	31%	22%	21%	27%	33%	26%
Once a day	7%	8%	6%	11%	15%	10%

χ^2 (12, N = 1229) = 35.42, $p < 0.0004$

Occurrence of complaints per year of studying

In this paragraph the effect of the number of years of studying on the occurrence of WRULD was analysed. In Table 3.2, the percentages of complaints per year of studying are shown as a function of level of occurrence. There are no clear differences in the levels of occurrence of complaints over the years of studying. The effect over the years of studying is not significant although close to. However, complaints seem to occur most frequently in students who study in their 2nd year (29% once a week and 16% once a day and combined 5th, 6th and 7th years (32% once a week and 12% once a day).

Table 3.2. Occurrence of complaints in percentage of the group respondents with complaints within the years of studying. N = 1221

year	1st n = 607	2nd n = 131	3rd n = 187	4th n = 161	5th/6th/7th n = 135	All N = 1221
Once a year	17%	12%	17%	17%	21%	17%
Once a month	48%	43%	47%	53%	35%	47%
Once a week	26%	29%	29%	23%	32%	27%
Once a day	9%	16%	7%	7%	12%	10%

χ^2 (12, N = 1221) = 20.92, $p = 0.0516$

Duration of complaints in successive academic years

The duration of students' WRULD complaints was obtained by a 6-alternative forced task: 'continuous', 'a couple of days', '12-24 hours', '6-12 hours', '1-6 hours', 'and less than 1 hour'. They only chose one level. In Table 3.3, the percentages of complaints per academic year are shown as a function of duration level. As can be seen in the right-most column most students experienced complaints lasting for less than 1 hours (52%) and 1-6 hours (31%). There is a significant effect of the duration of the complaints over the academic years. In the academic year 2008/2009 the percentage students experiencing complaints 'of less than 1 hour' is highest (58%). Percentages of complaints lasting more than 12 hours (12-24 hours, a couple of days, and continuous) are highest in the academic year 2004/2005 (15%), 2008/2009 (12%) and 2013/2014 (16%).

Table 3.3. Duration of complaints in percentage of the group respondents with complaints within the successive academic years.

	2004/2005 n = 209	2006/2007 n = 260	2008/2009 n = 244	2010/2011 n = 292	2013/2014 n = 269	All N = 1274
Less than 1 hour	49%	53%	58%	54%	45%	52%
1-6 hours	29%	32%	27%	31%	35%	31%
6-12 hours	6%	5%	2%	8%	4%	5%
12-24 hours	6%	3%	3%	2%	3%	3%
A couple of days	7%	5%	6%	3%	7%	5%
Continuous	2%	1%	3%	2%	6%	3%

$\mathcal{X}^2 (20, N = 1274) = 41.37, p = 0.0033$

Duration of complaints per year of studying

The duration level of the complaints was also analysed per year of studying. Table 3.4 shows the percentages of complaints per year of studying as a function of duration level. There is a significant effect of the duration of the complaints over the years of studying. The complaints of students who have been studying for more than one year last longer than those of students who are studying in their 1st year. This can be seen by the low percentage of complaints of more than 6 hours in the 1st year of studying (11%) as compared to 21% in the 2nd year, 25% in the 3rd year, 21% in the 4th year, and 22% in the combined 5th/ 6th/ 7th year of studying. The percentage of complaints lasting more than 24 hours (a couple of days and continuous) is highest in the 2nd (15%) and 3rd (12%) year of studying.

Table 3.4. Duration of complaints in percentage of the group respondents with complaints within the years of studying.

year	1st n = 628	2nd n = 138	3rd n = 190	4th n = 168	5th/6th/7th n = 142	All N = 1266
Less than 1 hour	61%	46%	44%	46%	38%	52%
1-6 hours	28%	33%	31%	33%	39%	31%
6-12 hours	4%	4%	6%	6%	6%	5%
12-24 hours	1%	2%	7%	7%	7%	3%
A couple of days	3%	7%	9%	6%	8%	5%
Continuous	3%	8%	3%	2%	1%	3%

$\mathcal{X}^2 (20, N = 1266) = 86.57, p < 0.0001$

Seriousness OxD in successive academic years

The seriousness of students' WRULD complaints was calculated as the multiplication of the occurrence x duration and expressed in the total number of hours per year in which respondents experienced complaints. Respondents chose one option from a 7-alternative forced task: '1-50 hours', '50-100 hours', '100-200 hours', '200-400 hours', '400-800 hours', '800-1600', and '> 1600 hours'. Table 3.5 presents the percentages of complaints per academic year as a function of seriousness OxD level. There is a significant effect of the seriousness of the complaints over the academic years. Over the five academic years, the less severe complaints of 1-50 hours per year are seen most (58%, see right-most column), and is true for all recorded years in particular the year 2008/2009 (69%). The highest percentage of more serious complaints of more than 200 hours per year were found in the years 2004/2005 (19%) and 2013/2014 (23%). The highest percentage of students experiencing complaints of > 1600 hours per year was found in the academic year 2013/2014 (9%).

Table 3.5. Seriousness OxD of complaints in percentage of the group respondents with complaints within the academic years. The indicated number of hours are the calculated hours per year in which respondents experienced complaints.

	2004/2005 n = 198	2006/2007 n = 247	2008/2009 n = 234	2010/2011 n = 282	2013/2014 n = 251	All N = 1212
1-50 hours	56%	64%	69%	56%	45%	58%
50-100 hours	17%	14%	12%	15%	18%	15%
100-200 hours	9%	10%	8%	15%	14%	11%
200-400 hours	3%	4%	4%	4%	4%	4%
400-800 hours	5%	2%	2%	2%	4%	3%
800-1600 hours	5%	4%	2%	5%	6%	4%
> 1600 hours	6%	2%	3%	3%	9%	5%

χ^2 (24, N = 1212) = 53.47, p = 0.0005

Seriousness OxD per year of studying

The analysis of the seriousness OxD of complaints over the years of studying is reflected in Table 3.6. There is a significant effect of the seriousness OxD over the years of studying. The percentage of less severe complaints of 1-50 hours per year is highest in the 1st (61%) and 4th (61%) year of studying. The highest percentage of more serious complaints (> 200 hours per year) are experienced by the students in their 2nd (25%) followed by the students in the combined 5th/ 6th/ 7th year of studying (20%). The highest percentage of students experiencing complaints of > 1600 hours was found in the 2nd year of studying (10%).

Table 3.6. Seriousness OxD of complaints in percentage of the group respondents with complaints within the years of studying. The indicated number of hours are the calculated hours per year in which respondents experienced complaints.

year	1st	2nd	3rd	4th	5th/6th /7th	All
	n = 598	n = 131	n = 181	n = 159	n = 135	N = 1204
1-50 hours	61%	48%	54%	61%	50%	58%
50-100 hours	16%	17%	13%	11%	18%	15%
100-200 hours	10%	11%	15%	11%	13%	11%
200-400 hours	3%	5%	5%	5%	4%	4%
400-800 hours	2%	3%	4%	5%	4%	3%
800-1600 hours	4%	7%	3%	4%	7%	4%
> 1600 hours	4%	10%	6%	3%	5%	5%

$\mathcal{X}^2$ (24, N = 1204) = 37.80, p = 0.0363

Seriousness LDA in successive academic years

The alternative investigation on the seriousness of the WRULD complaints was based on the questioned limitation of seven daily activities. These were, writing, holding a book while reading, holding a telephone, opening a jar, carrying a bag, button up clothes and teeth brushing. For each activity, there was a theoretical scaling based on a 5-alternative forced task: 1 'no difficulty', 2 'some difficulty', 3 'quite some difficulty', 4 'very much difficulty', 5 'impossible'. The average score (seriousness LDA) implicated the total scores for all seven daily activities divided by seven. In Figure 3.5, a bar chart presents students' limitation of daily activities as a function of academic year.

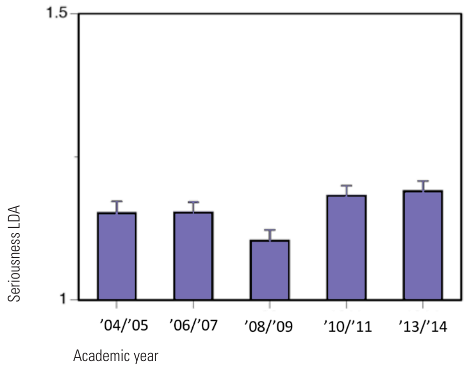

Figure 3.5. Seriousness LDA; average score and standard error of the theoretical scaling of the seriousness of complaints expressed in limitation of daily activities within the successive academic years, '04/'05 (n=203), '06/'07 (n=257), '08/'09 (n=241), '10/'11 (n=285), '13/'14 (n=260). Only respondents with complaints. One-way ANOVA. N = 1246.

The seriousness LDA over all five academic years is 1.16. There is a significant effect of the seriousness LDA over the academic years (F(4,1241) = 3.52, p = 0.0073). Students in the academic years 2010/2011 and 2013/2014 had more difficulties with their daily activities (respectively 1.18 and 1.19) as compared to the years 2004/2005 (1.15) and 2006/2007 (1.15). The lowest average score is measured in the year 2008/2009 (1.10).

Seriousness LDA per year of studying

Students' limitation of daily activities as a function of year of studying is presented in the bar chart of Figure 3.6. There is a significant effect of the seriousness LDA over the years of studying (F(4,1233) = 2.38, p = 0.049). The average score is higher in students studying multiple years (2nd - 1.17, 3rd - 1.18, 4th - 1.15, 5th/6th/7th - 1.21) as compared to students in their 1st year (1.14) although there is a slight decrease in students studying in their 4th year.

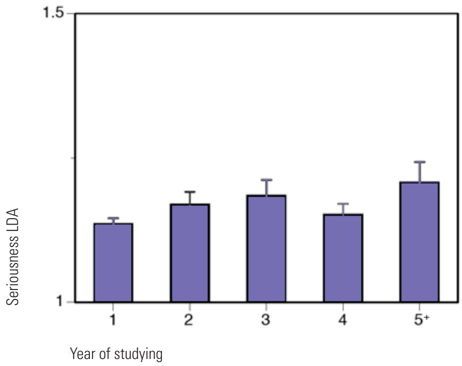

Figure 3.6. Seriousness LDA; average score and standard error of the theoretical scaling of the seriousness of complaints expressed in limitation of daily activities within the successive years of studying, 1 (n=615), 2 (n=130), 3 (n=189), 4 (n=170), 5^{+} (n=134). The years of studying 5^{+} contains students who study in their 5th, 6th or 7th years. Only respondents with complaints. One-way ANOVA. N = 1238

Comparison of the two types of seriousness of complaints; seriousness OxD versus seriousness LDA

The seriousness OxD in relation to seriousness LDA is indicated in Table 3.7. There is a significant effect of the seriousness OxD on the seriousness LDA. The average score in limitation of daily activities is higher in respondents suffering more hours per year from WRULD complaints, e.g. 1.10 for students experiencing 1-50 hours complaints in comparison to 1.47 for students experiencing >1600 hours complaints. Nevertheless, in respondents experiencing 100-200 hours complaints per year the average limitation of daily activities is relatively high (1.27).

Table 3.7. Comparison of two types of seriousness of complaints: seriousness OxD (occurrence x duration) and seriousness LDA (limitation of daily activities). Only respondents with complaints.

		n = 677	n = 181	n = 131	n = 44	n = 34	n = 47	n = 55	N = 1169
seriousness OxD	hrs	1-50	50-100	100-200	200-400	400-800	800-1600	>1600	All
seriousness LDA Mean/SE		1.10/.01	1.12/.02	1.27/.02	1.15/.04	1.24/.05	1.41/.04	1.47/.04	1.15
F (6,1162) = 30.10, p < 0.0001									

Body locations of complaints

The respondents could indicate multiple body locations where they experienced WRULD complaints. The results of all academic years and all years of studying together are shown in Figure 3.7. The regions in the body that were indicated most often were, neck (58%), shoulders (53%) and back (43%), followed by wrist (41%).

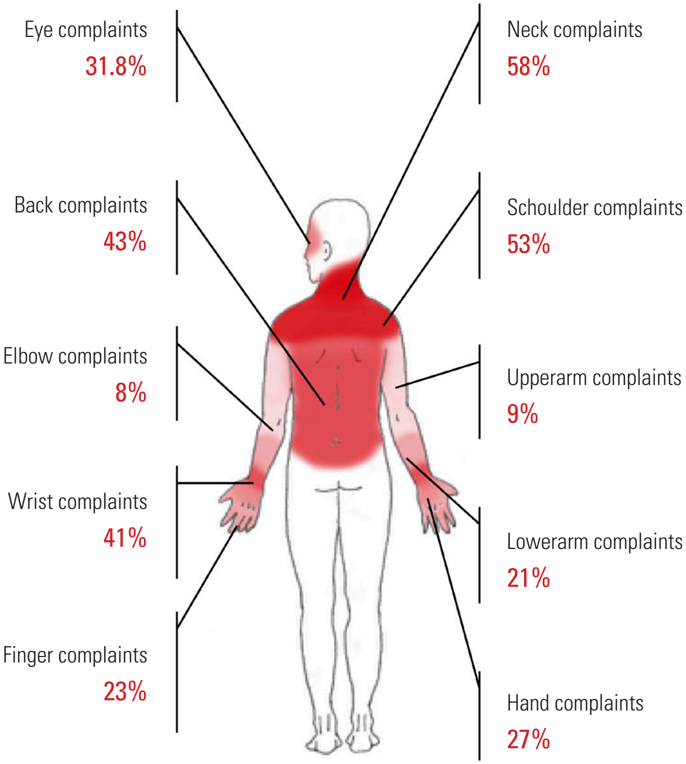

Figure 3.7. Body locations of complaints in percentages of the group respondents with complaints

Average number of computer working hours per day in successive academic years

The average number of computer working hours per day (whether for study, work or leisure) was questioned to the total respondents group. Respondents chose one option from a 5-alternative forced task: '0-1 hours', '1-2 hours', '2-4 hours', '4-6 hours', and '> 6 hours'. Table 3.8 presents the percentages of respondents per academic year as a function of average computer working hours per day. There is a significant effect in the average number of computer working hours per day over the academic years. The percentage of more than 4 computer working hours per day increases every academic year (2004/2005 - 28%, 2006/2007 - 38%, 2008/2009 - 42%, 2010/2011 - 47%, and 2013/2014 - 60%). The percentage of more than 6 computer working hours per day is highest in 2013/2014 (30%).

Table 3.8. Average number computer working hours per day in percentage of the total respondents group within the academic years. Total respondents group. N = 2181

	2004/2005 n = 332	2006/2007 n = 423	2008/2009 n = 427	2010/2011 n = 543	2013/2014 n = 456	All N = 2181
0-1 hours	7%	4%	2%	1%	0%	2%
1-2 hours	23%	16%	15%	9%	10%	14%
2-4 hours	42%	43%	41%	43%	29%	40%
4-6 hours	23%	26%	32%	34%	30%	30%
> 6 hours	5%	12%	10%	13%	30%	14%
$\mathcal{X}^2$ (16, N = 2181) = 199.84, $p < 0.0001$						

Average daily number of computer working hours per years of studying

The percentages of respondents per year of studying as a function of the questioned average computer working hours per day is shown in Table 3.9. There is a significant effect in the average number computer working hours per day over the years of studying. The more years students have studied, the more hours they work with the computer. Except for the 2nd year of studying (having a relatively high percentage) the percentage of students spending more than 4 hours per day in front of the computer increases gradually every year of studying (1st – 30%, 2nd – 69%, 3rd – 53%, 4th – 66%, 5th/6th/7th - 76%).

Table 3.9. Average number computer working hours per day in percentage of the total respondents group within the years of studying. Total respondents group. N = 2156

year	1st n = 1269	2nd n = 208	3rd n = 268	4th n = 218	5th/6th/7th n = 193	All N = 2156
0-1 hours	4%	0%	0%	0%	0%	2%
1-2 hours	20%	2%	7%	4%	4%	14%
2-4 hours	46%	29%	40%	31%	20%	40%
4-6 hours	24%	40%	37%	38%	35%	30%
> 6 hours	6%	29%	16%	28%	41%	15%
$\mathcal{X}^2$ (16, N = 2156) = 425.65, $p < 0.0001$						

Risk factors: Relation between prevalence and number of computer hours per day

The analysis was made to investigate a relationship between the number of computer hours per day and the prevalence of complaints. In Figure 3.8, a mosaic graph presents the proportion of students experiencing WRULD complaints as a function of computer working hours per day. There is a significant effect ($\mathcal{X}^2$ (4, N = 2181) = 31.16, $p < 0.0001$) between the prevalence of complaints and the reported average number of computer working hours per day. The higher the reported average number of computer hours per day, the higher is the percentage of students experiencing complaints. The lowest percentage of complaints (40%) is found in students working 0-1 hours per day with the computer and the highest (72%) in students who work more than 6 hours per day.

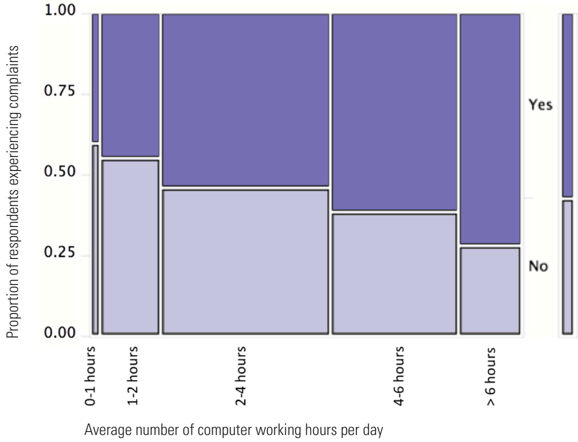

Figure 3.8. Proportions of students experiencing complaints as a function of computer working hours per day, 0-1 hours (n=52), 1-2 hours (n=304), 2-4 hours (n=863), 4-6 hours (n=646), > 6 hours (n=316). Total respondents group. N = 2181

Risk factors: Relation between seriousness OxD and the number of computer hours per day

In this last analysis the relationship between the seriousness OxD of the complaints and the reported average number of computer working hours per day was investigated. The results are presented in Table 3.10. There is a significant effect between the seriousness OxD of the experienced complaints and the reported average number of computer working hours per day. Students experiencing more serious complaints of more than 100 hours per year work more often > 4 hours per day with the computer (100-200 hours - 61%, 200-400 hours - 54%, 400-800 hours - 64%, 800-1600 - 66%, and > 1600 hours - 60%) in comparison to students experiencing less severe complaints of less than 100 hours per year (1-50 hours - 47%, 50-100 hours - 44%). Nevertheless, these students experiencing complaints of more than 100 hours per year have relatively high percentages of students that work for only 0-1 hours and 1-2 hours per day with the computer.

Table 3.10. Relation between the seriousness OxD of the experienced complaints and the reported average number of computer working hours per day. Complaints group.

hours	0 – 1 n = 21	1 – 2 n = 131	2 – 4 n = 437	4 – 6 n = 380	> 6 n = 207	All N = 1176
1-50 hours	2%	12%	39%	32%	15%	58%
50-100 hours	1%	11%	45%	29%	15%	15%
100-200 hours	2%	8%	29%	40%	21%	11%
200-400 hours	2%	11%	33%	28%	26%	4%
400-800 hours	0%	8%	28%	33%	31%	3%
800-1600 hours	0%	12%	22%	39%	27%	4%
> 1600 hours	4%	9%	27%	31%	29%	5%

$\mathcal{X}^2$ (24, N = 1176) = 19.45, p = 0.0280

> DISCUSSION

We will discuss the results in four sections. The first addresses the differences between academic years. The second presents possible reasons that explain differences between academic years. The third addresses how WRULD evolve over the number of years of studying, and the fourth addresses possible explanatory factors causing differences between years of studying. Finally, we compare our outcomes with previous findings in the last section.

Differences between academic years

In the time-period 2004-2014 a decrease in the prevalence, occurrence, duration and the two alternative measures for the seriousness of WRULD have been observed from the first (2004/2005) to the third (2008/2009) or fourth (2010/2011) recorded academic year followed by an increase of these values to the fourth or fifth academic year (2013/2014). In this last academic year 2013/2014, the prevalence is only slightly lower than the highest level in 2004/2005. The seriousness OxD (and also its separate factors occurrence and duration) and seriousness LDA show the highest scores in the last academic year 2013/2014.

The complaints group data of all academic years (and all years of studying) show a clear relationship between the seriousness OxD and the seriousness LDA indicating that the limitation in daily activities is higher in respondents suffering more hours per year from WRULD complaints.

Possible explanatory factors causing differences between academic years.

This aggravation of WRULD in the last academic years cannot be explained by the increase of daily computer working hours spent by students every academic year as observed in this study and the in this study confirmed relationships between both WRULD prevalence / reported daily computer working hours and seriousness OxD of WRULD complaints / reported daily computer working hours. Because initially, WRULD amongst IDE students seemed to ameliorate during the first three years of our measurements despite the students' increasing daily computer working hours. As discussed in the previous study [9] on WRULD amongst IDE students and in parallel to the possible effect of the previously discussed nation-wide attention for work-related causes and prevention measures in the professional work environment [1], the IDE prevention programme [9] may have contributed to this reduction of WRULD problems over the first three or four academic years. Can we distinguish which internal and external factors of the IDE student community have contributed to the aggravation of WRULD starting from 2008/2009?

Several far-reaching developments in the study regulations might have contributed to these changes in the WRULD figures. The Bachelor-before-Master rule has been

enforced at Delft University of Technology in September 2010, after a negotiation period starting in 2006. Up to then, it was possible for students who had not yet completed their Bachelor's degree programme to start a Master's degree programme at the same institution. Since the implementation of the Bachelor-before-Master rule, students had to finalise their total Bachelor programme before starting their Masters. The rule was implemented nation-wide in 2012 when it was incorporated into the Dutch Higher Education and Research Act (WHW). Another important measure in particular for the 1st year students, was the Binding Recommendation on the Continuation of Studies (BSA) introduced in September 2009. Students had to attain a minimum number of credits (starting with 50% in 2009 and tightened to 75% in 2012) in their first Bachelor year in order to be allowed to continue with their studies. In the same period of time the study grant (= studiefinanciering in Dutch) was abolished. In September 2012 the grant for only Master students was replaced by a loan system and in autumn 2015 as well for new 1st year students. These three measures were not yet in force in the early recorded academic years 2004/2005 up to 2006/2007. It is most likely that these three societal measures have increased the study load and consequently stress for students.
The relationship between stress and the occurrence of WRULD amongst adolescents and students has been established in former studies [15, 16].

Differences between years of studying

Regarding the WRULD related trends in the years of studying there is clear difference between students studying in their 1st year as compared to students studying multiple years. The values for prevalence, seriousness OxD (and its separate factors occurrence and duration) and seriousness LDA are lower in students who just started studying as compared to students who have been studying for a longer time. The prevalence of WRULD increases up to the 4th year of studying and shows a slight reduction in the combined 5th/6th/7th year. The occurrence, duration and consequently the seriousness OxD show the highest values for the 2nd year of studying and the second highest for the combined 5th/6th/7th year of studying. The seriousness OxD in the 4th year of studying is relatively low. When considering the alternative seriousness LDA, the inhibition increases in the first three years and shows as well a reduction in the 4th year of studying and the highest value for inhibition in the combined 5th/6th/7th year of studying.

Possible explanatory factors causing differences between years of studying

The low prevalence rate of complaints in students in their 1st year as compared to students studying multiple years is expected and similar to the results in the former study on WRULD amongst IDE students [9]. These 1st year measurements were taken around the second month of their studies so students didn't meet many deadlines yet and spent the least daily computer working hours from all years of studying. The gradual increase of WRULD complaints prevalence throughout the higher years goes in parallel with the gradually increasing daily computer time in higher years of studying. The question stated in the former study [9], whether the higher percentage of students experiencing complaints in higher years of studying was related to the higher reported average number of computer hours per day in these years, can be positively answered. However, more aspects might play a role in the increasing prevalence in higher years of studying, such as the high study load of the master programme, their improved commitment and responsibility towards clients and peers in real-life projects, and perhaps also the more tangible financial consequences of their studying. The slight reduction in WRULD prevalence in students in their $5^{th}/6^{th}/7^{th}$ year of studying is standing out of this pattern and might be explained by students' improved freedom in organising their study activities. Most students in their 5th/6th/7th year of studying are enabled to choose courses of interest, to define their individual graduation project, to alternate between tasks and between study and non-study related activities.

The effect of the seriousness OxD over the years of studying and the increase in seriousness OxD in the 2^{nd} and combined $5^{th}/6^{th}/7^{th}$ year of studying was not found in the previous study on IDE students [9], but are in line with the observed high scores of daily computer working hours in these years of studying. However, the scores of both the seriousness OxD and seriousness LDA gives an opposite picture in the 4^{th} (relatively low scores) and $5^{th}/6^{th}/7^{th}$ year of studying (relatively high scores) as compared to the aforementioned prevalence rates. A possible explanation could be that students in the 4^{th} year of studying may have learned how to cope with their WRULD risk factors within the IDE environment and prevent them from getting worse. For students in the combined $5^{th}/6^{th}/7^{th}$ year of studying on the other hand, their WRULD complaints history, the pressure to finalise all courses, to find a suitable graduation project, and to bring their master study to a successful conclusion might contribute to aggravation of the complaints.

Comparison with previous findings

The body locations of the complaints that were most often indicated by the complaints group in this study were, the neck (58%), shoulders (53%) and back (43%), followed by wrist (41%). The results of all body locations can be seen in Table 3.11 together with the

Table 11. Percentages of complaints per body locations - in relation to the group respondents with complaints.

	Eyes	Neck	Shoulders	Back	Upper arm	Elbow	Lower arm	Wrist	Hand	Fingers
2004-2014 complaints group N = 1293	30,8%	58,2%	53,4%	43,2%	8,7%	8,2%	21,2%	40,9%	27,5%	23,1%
2002/2003 complaints group N = 92	34,8%	54,3%	55,4%	38,0%	7,6%	14,1%	26,1%	60,9%	30,4%	28,3%

results of the academic year 2002/2003 as described in the former study on IDE students [9]. Percentages are taken in comparison to only the respondents group with complaints. The results of the 2002/2003 measurements show similar percentages for most body locations. Nevertheless, the (2004-2014) study of this paper shows a lower percentage of wrist complaints.

Highest prevalence rates of neck and shoulder complaints were also found in the studies of Palm et al. [5] on upper secondary school students and in the study of Hakala et al. [13] on adolescents. Also Noack-Cooper et al. [6] found in their study on college students the neck region to be the most common site of frequent discomfort and pain.

As stated at the start of this discussion, the association of self-reported average number of computer working hours and the prevalence of WRULD symptoms as found in other studies [5, 10-12] was confirmed in our findings. The higher the reported average number of computer hours per day, the higher is the percentage of students experiencing complaints. Also the relationship in the Hakala et al. study [13] between the self-reported average number of computer working hours and the seriousness of WRULD symptoms was confirmed in our study based on the found relationship between computer hours and seriousness (OxD). Nevertheless, students experiencing more serious complaints (of more than 100 hours per year) have relatively high percentages of students that work little hours (0-1 hours and 1-2 hours per day) with the computer. Their complaints might hinder their long-term working with the computer.

Boström et al. found in their study [7] among young adults that pain, ache, numbness or tingling symptoms in the upper back, neck and upper extremities had a relation with self-reported generally reduced productivity. In the (2004-2014) study of this paper, these body locations were also investigated and subjects experienced similar complaints (pain, numbness, tingling). So, it is probable that the complaints found in our study influenced students' productivity as well. The economic consequences for both the individual student, the government as well for the university, of students who were no longer even able to study (their entire programme) due to WRULD were previously described and estimated for the student population of Delft University of Technology [9].

At the beginning of this paper we saw the decreased reporting of WRULD between 2001 and 2018 in the occupational environment of The Netherlands [1, 2]. It is tempting to compare these results with our results of the Dutch student population. Unfortunately, this comparison does not hold because the investigated population of the Dutch Centre for Occupational Diseases includes beside computer-related occupations also professions in e.g. the transport, industry, and construction sectors. There are also differences in the body locations studied. However, we learned from these professional figures that structural attention for causes and prevention measures for WRULD in computer work possibly contributed to the downward trend. It seems that we can also bring about such a WRULD prevalence decrease in the educational environment as was also shown in the studies of Jacobs et al. [3, 4]. Such a positive trend in the prevalence but also in the severity of the complaints appeared to have been initiated in the first academic years of our study, possibly as a result of the structural attention for WRULD prevention and risk factors within the student environment of our focus [9]. Looking at the extent and severity of WRULD complaints during the last academic years of our study, it seems that governments should be cautious about (the introduction of) loan systems combined with limitations on study time in view of not only a healthy student population but also a healthy well educated group of young professionals entering the market.

The effects on WRULD of the actual societal change in students' lives due to the COVID-19 restrictive measures and related increase of stress, still need to be investigated. However, from the first short term studies on this actual topic we can deduce that the pandemic seems to have both positive and negative effects on physical complaints of computer workers. Celenay et al. [17] showed that due to COVID-19 individuals in Turkey of the age group 20-65 who stayed at home compared with those who continued to go to work had more low back pain problems. Nevertheless, this increase was not shown at all regions; rates of neck, upper-back, and shoulder pain were lower. Another study in Turkey on individuals aged between 12-78 years conducted by Sengul et al. [18] showed a small decrease in the frequency of pain and discomfort in multiple body regions and a small increase of the severity of pain and discomfort in body regions - (lumbar) back region and the neck - during the quarantine when compared to the level before the quarantaine. A third Turkish study by Pekyavaş and Pekyavaş [19] on the age group 18-50, showed that individuals working at home during the COVID-19 pandemic developed moderate shoulder and low back pain. The study of Leirós-Rodríguez et al. [20] on university students during the Spanish lock down between the months March and May 2020, found a musculoskeletal pain increase of the middle (dorsal) region of the back and in both shoulders (this region only in woman) and a reduction of pain in the elbows, hands and one of the shoulders during the lockdown in which students had transitioned from classroom learning to online learning. If we look at these studies, it seems that back pain increased in the situation of online working from home and that more distal upper limb disorders decreased. Nevertheless, further research is needed to investigate the effects of COVID-19 on WRULD amongst students.

> LIMITATIONS OF THE STUDY

There are some limitations which might have influenced the outcomes of the research. The awareness for WRULD might have been high in particular for the first year student group, because these questionnaires were handed out at the end of a WRULD prevention information session. This might have influenced the awareness of participants' complaints. However, this was done every year which means that trends in time are still valid.

Unfortunately, we did not continue with the questionnaires after 2014. However, our results show that the data on prevalence and seriousness is quite consistent over the investigated academic years, beside the fluctuations attributed to the described societal changes. Since we are not aware of such substantial societal changes within the period 2014 up till 2020, we might assume that the result would not have been too different as compared to our last measured academic year.

Another limitation is that the meaning of the questioned term 'computer' has changed over the time span 2004-2014. Starting with mainly desk top computer stations, it transformed to more and more mobile solutions via laptops, tablet and smart phones. Honan [21] described that these changes evoked a shift to working from anywhere imaginable and ever-present access to data over the internet. She indicated that additional risks have been introduced to the neck, thumbs and hands when using mobile devices, which might have influenced our outcomes.

The reported computer working hours and associated complaints do not distinguish between computer work for study, work and leisure. The study-related causes mentioned in the discussion might not be totally valid, because leisure activities could be relevant as well. On the other hand the intermingling of study, work and leisure activities is a reality and preventive interventions might impact all.

> CONCLUSION

More than half of the students surveyed between 2004-2014 experienced WRULD symptoms, especially in the neck, shoulder, back and wrist. The highest prevalence rates were found in the first and last recorded academic years. Also the highest percentages of more serious complaints (based on the multiplication of their reported occurrence and duration of their complaints as well as their limitation in seven daily activities) were found in these academic years. The prevalence of complaints among students raises from their 1^{st} to their 4^{th} year of studying. Both measures for the seriousness of the complaints show highest scores in students who are studying in their year $5^{th}/6^{th}/7^{th}$ year. Relations were found between the reported number daily computer hours and WRULD prevalence and the reported number daily computer hours and the seriousness of the WRULD complaints. However, not all results could be explained on the basis of the reported computer time spent. Societal changes like the introduction of loan systems combined with limitations in study time may have played an even more important role. It is very likely that the societal changes in students' lives resulting from COVID-19 are also driving a change in WRULD amongst students. Our study confirmed that structural attention for WRULD prevention and risk factors seems to be effective in reducing the number and severity of WRULD complaints. For these reasons, prevention programmes remain important and must be adapted to the recent societal changes.

> ACKNOWLEDGEMENT

We are appreciative for the voluntarily participation in this study of two-thousand-two-hundred-and-fifty-four (2254) students Industrial Design Engineering. Additionally, we would like to thank Cesar therapists Cees Verhoeven and Jeroen Hutten and the involved IDE staff members to help distributing and collecting the questionnaires. Furthermore, we are grateful to Henk Van der Molen and colleagues of the Dutch Centre for Occupational Diseases for allowing us to include the figures on reported occupational diseases related to upper limb disorders in our article. And we are very thankful to Renate De Bruin (now owner of Erin Ergonomics and Industrial Design), who started a questionnaire on the WRULD topic already in 1999, helped evolving the questionnaire as used in our study and advised on several aspects of this paper.

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CHAPTER 4a

BLOOD FLOW CHANGES IN RSI SUBJECTS: AN INTRODUCTION OF A PEN WITH BIOFEEDBACK

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> ABSTRACT

Impaired blood flow is seen as one of the main causes of Repetitive Strain Injuries (RSI) in the upper limbs. Several physiological mechanisms were proposed in literature as an explanation for the impeded circulation. This paper describes an alternative mechanism responsible for the reduced blood flow in the whole arm, originating at the costoclavicular gate, where the subclavian artery and vein leave the thorax and enter the upper limb. In the long run this may cause a cascade of effects resulting in pain and dysfunction in the more distal parts of the arm. Furthermore, a sensor pen is developed based on this explanation. It is hypothesised that the use of the pen relaxes the relevant muscles to increase the blood flow. In this way, the sensor pen may function as an over all tension feedback device for the user. The presented explanation and functioning of the pen will be investigated in future studies.

> INTRODUCTION

Various underlying mechanisms were suggested in literature to explain the cause of Repetitive Strain Injuries (RSI) - a medical syndrome affecting the neck, upper back, shoulders, arm or hand, or a combination of these areas. They relate to abnormalities affecting the muscles, nerves and tendons, or even the central nervous system, separately or in combination. There are multiple possible mechanisms that do not form a complete explanation and that are not sufficiently supported by empirical data [1]. Still, more scientific research into the pathophysiology of RSI is needed to formulate effective preventive policies. Moreover this will enable industry to design effective RSI preventive products or systems. From a medical or a human perspective it would be very helpful to find a physiological predictor of RSI.

There is mutual consensus concerning the risk factors of heterogeneous RSI complaints such as stiffness, paresthesia, numbness, loss of power, ischaemia and pain. These are preceded by activities that involve repeated movements, excessive use of force, awkward positions and static strain - keeping one or more body parts for longer time in a static position [2]. In addition, long hours of repetitive movements [3] and precision demands of the task [1] are also indicated. Psychosocial factors such as pressure of work, high levels of stress, high working tempo, mentally demanding work and inadequate social support do not themselves lead to RSI problems, but contribute to an improved risk on RSI. On the other hand almost nothing is known about the extent to which personal factors (such as physical build and ability to handle stress) help to determine an individual's chance to develop RSI [2].

Blood flow

Reduced blood supply in the upper extremities is one of the main causes of RSI [4]. Several physiological mechanisms were proposed as an explanation for the impaired blood flow. It is usually ascribed to static contractions of the muscles in neck and shoulders [5]. The assumption is that the mechanical pressure in the muscles reduces the diameter of the blood vessels. Consequently, the blood flow through the whole arm will be affected. In other studies the focus is on the muscle motor units of distal areas of the arm [6]. These small parts of the arm muscles are almost constantly in use. Therefore the complaints may also result from lower force exertions (e.g., common in computer work). Overloaded muscles can still occur in these circumstances, because the subject is not aware of any over all feeling of muscle fatigue. In the aforementioned muscle related perspectives, the assumption is that inefficient blood flow to and in the muscles will lead to anaerobe metabolism. Consequently, a deficit in substrates (including oxygen) and an accumulation of metabolites (mainly lactic acids) will result. In prolonged contractions these acids cause discomfort and finally pain. These complaints can be intensified because a decrease in muscular microcirculation might lead to the sensitisation of pain receptors (nociceptors) in the muscle, meaning that low threshold stimuli can activate the pain system [7]. Armstrong et al. [8] found that reduction in muscle blood flow will lead to a cascade of responses in other body tissues (e.g., degeneration of the tendons and impaired circulation in the nerves), resulting in a range of complaints characteristic for RSI.

Alternative explanation for blood flow reduction

An alternative explanation[1] for blood flow reduction in people with RSI will be presented here. Starting point is that the flow impairment is not caused by mechanisms in the proximal or distal muscles, but at the costoclavicular gate where the artery and vein enter the upper limb (Figures 4a.1 and 4a.2).

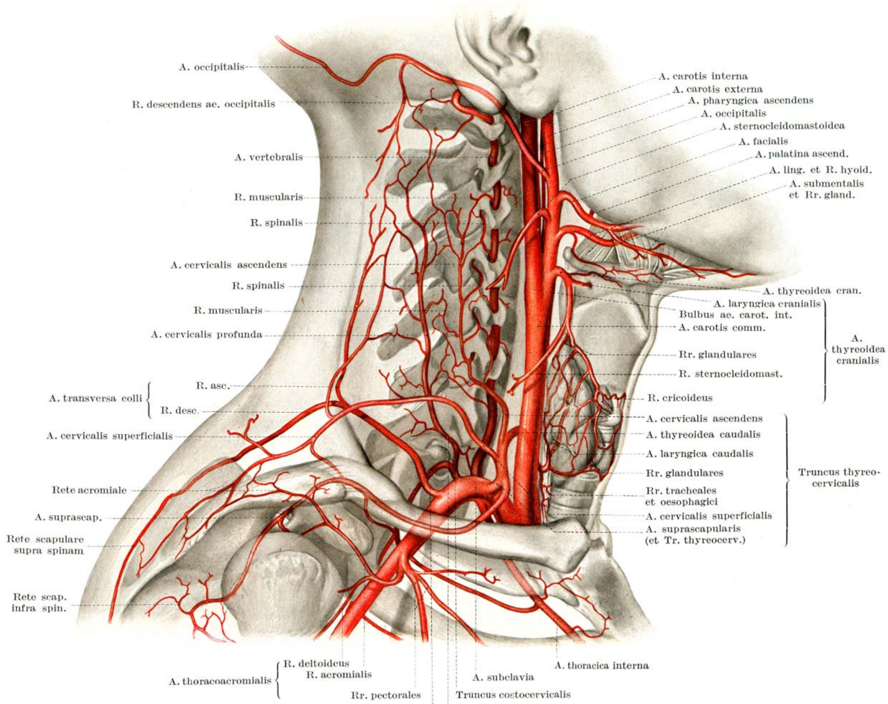

Figure 4a.1. The arterial system in relation to the costoclavicular gate (restricted by the subclavia and the first rib)

1 The second author of this article developed this explanation. He has his own physiotherapist consultancy. Furthermore he was researcher at Erasmus MC in 2004.

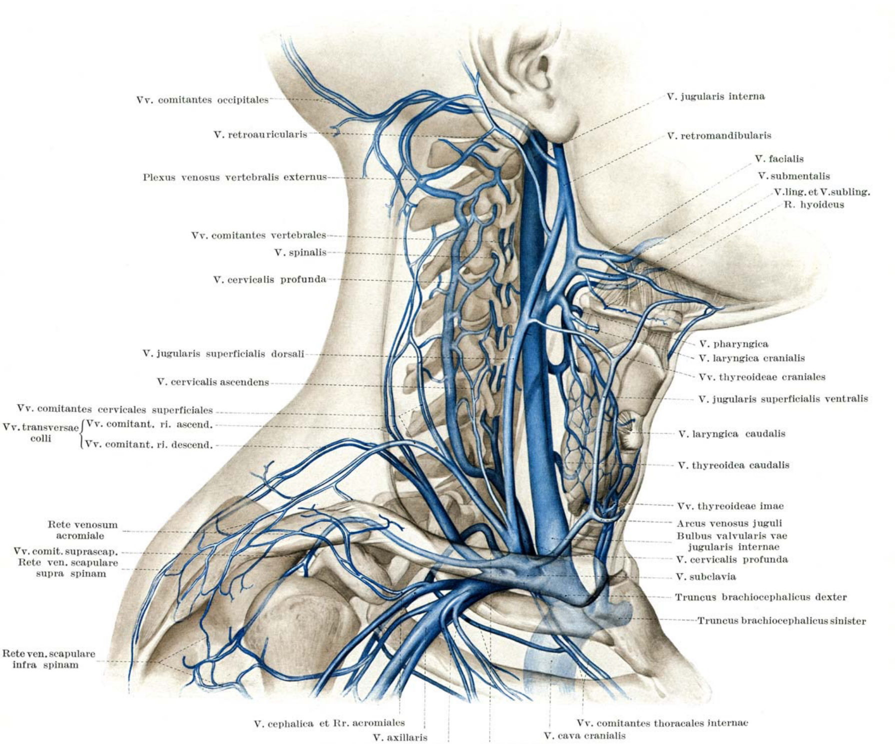

Figure 4a.2. The venous system in relation to the costoclavicular gate

Prolonged posture and stress result in sustained static contractions. These contractions might create high tension in the deep neck muscles (mm. scaleni), which are attached to the first rib. Increased tension in the deep neck muscles results in lifting the first rib, causing a hypothetical decrease in the costoclavicular space between the first rib and the clavicle. Consequently, a constriction of the subclavian vein and artery may occur. Therefore, a decreased blood flow to the upper limb will result. In the long run this may cause a cascade of effects in the more distal parts of the arm.

The sensor pen

A new device based on this explanation is the so-called sensor pen, developed by the second author and evolved within the company Tensor (www.tensorpen.com). The sensor pen (Figure 4a.3) is a classical writing pen equipped with biofeedback.

Figure 4a.3: The sensor pen

The shaft of the pen contains a sensor, registering the force and pressure in the hand while writing. When the user applies too much pinch force on the shaft, a red light in the top of the pen will warn the writer. By reducing the pinch force the light will switch off. The user is asked to write with the pen and to attempt to keep the light off. When the pen is used properly, the method of writing is altered in such a way that less muscular grip force is applied. In this manner, it is hypothesised that the use of the pen relaxes not only the hand muscles but may also affect all muscles of arm and neck. By relaxing the deep neck muscles, the space between the clavicle and the first rib might increase and the blood flow in the subclavian vein and artery might recover. In this way, the sensor pen may function as an over all tension feedback device for the user.

Future study

The presented explanation is plausible and the functioning of the pen renders promising results. However, further research is needed. There are several aspects to be investigated. The blood flow in the subclavian artery in a group of subjects with RSI when compared to a group of healthy controls will be tested. In addition the immediate and long-term effect in blood flow after writing with the sensor pen will be part of a future study.

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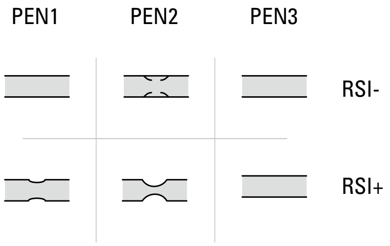
CHAPTER 4b

BLOOD FLOW CHANGES IN RSI SUBJECTS: INTERVENTION RESULTS OF A PEN WITH BIOFEEDBACK

> INTRODUCTION

In Chapter 4a [1] the role of impeded blood flow in the development of RSI symptoms is described and an alternative explanation for blood flow impairment in subjects with RSI is introduced, based on the assumed restriction at the costoclavicular gate - the space between the clavicle and the first rib where the artery and vein enter the upper limb - due to sustained static contractions in the neck muscles resulting from prolonged posture and stress. It was hypothesised that the use of a biofeedback pen providing the user visual feedback on its pinch force by means of a light signal at the pen top would relax the hand, arm and neck muscles and result in an enlarged costoclavicular opening and therewith increased blood flow in subclavian vein and artery. According to this hypothesis this effect would occur to a greater extent in people with RSI complaints than in people without RSI complaints, because of their assumed costoclavicular narrowing at baseline and even greater constriction during task stress. In this experiment the task stress was introduced by means of a writing task with a regular pen. This regular pen had the same geometry as the biofeedback pen used in this experiment. Blood flow was established in the subclavian artery. Figure 4b.1 shows the representation of this artery according to the alternative explanation in three conditions, at baseline (PEN1), while writing with the regular pen (PEN 2) and while writing with the biofeedback pen (PEN3), for both people without RSI complaints (RSI-) and people with RSI complaints (RSI+). According to the alternative explanation, it was also assumed that in PEN2 a temporary and slight narrowing of the gate may occur in healthy participants as a result of tightening of the neck muscles (indicated by the dotted line in RSI- in Figure 4b.1).



PEN1 = at baseline
PEN2 = while writing with the regular pen
PEN3 = while writing with the biofeedback pen
RSI- = people without RSI complaints
RSI+ = people with RSI complaints

Figure 4b.1. Hypothetical representation of the subclavian artery and constriction of people with and without RSI (investigated in this study at day 1), according to the alternative explanation for blood flow reduction.

In this chapter, the methods and results of the research into blood flow in these three conditions and in both groups are presented, compared and discussed. The level of blood flow was established by taking blood velocity and cross-sectional area (further abbreviated as 'section') measurements with echo-Doppler in the subclavian artery in the costoclavicular gate of the subjects.

The aim of this study was to investigate the following research questions,

> Are there differences in the arterial section, the blood velocity and consequently the blood flow in the subclavian artery in the costoclavicular gate between subjects with RSI complaints (RSI+) and subjects without RSI complaints (RSI-) in the three pen conditions (at baseline, while writing with the regular pen and while writing with the biofeedback pen)?

> Are there differences in arterial section, blood velocity and consequently the blood flow in the subclavian artery in the costoclavicular gate of subjects with RSI complaints (RSI+), in the three pen conditions, between baseline and after exercising with the biofeedback pen for a week?

> Are there differences in pain and paresthesia in subjects with RSI complaints (RSI+) between baseline and after one week of supervised usage of the biofeedback pen?

> Are there differences in severity, frequency, duration of complaints and limitations on general daily activities in subjects with RSI complaints (RSI+) between baseline and after one week of supervised usage of the biofeedback pen? And similar after an extra week of 'own' usage of the biofeedback pen?

> Do these results confirm the alternative explanation on reduced blood flow in people with RSI complaints?

> METHODS

Participants

Participants in the group of subjects with RSI complaints (RSI+) were students at the Delft University of Technology, mainly of the Faculty of Industrial Design Engineering (IDE). The control group of healthy subjects (RSI-) consisted of students and young adults from various studies and professions. At day 1 (see procedure) there were 13 participants of the RSI+ group aged 19-28 year (3 males and 10 females) and 24 participants of the RSI-group aged 19-26 year (11 males and 13 females). At day 5 (see procedure) there were 12 participants in the RSI+ group aged 19-28 year (3 males and 9 females). The general exclusion criteria for both groups related to blood flow influence were, diabetes mellitus, hypertension, hypercholesterolemia, fracture of the clavicle, cardio vascular diseases, having a pacemaker, use of medications that influence the vessels, and smoking more than 5 cigarettes per day. The RSI+ group had non-specific complaints of RSI, meaning long-term complaints of neck, shoulder, arm, elbow, wrist and/or hand. The affected arm did correspond to the writing arm, because the measurements were taken only on the writing hand. All subjects were asked not to drink caffeine-holding drinks within a period of an hour in front of the physiological examinations because of possible influence on the blood flow, and not to work in front of the computer within a period of half an hour before the examinations in order to create similar conditions for all subjects.

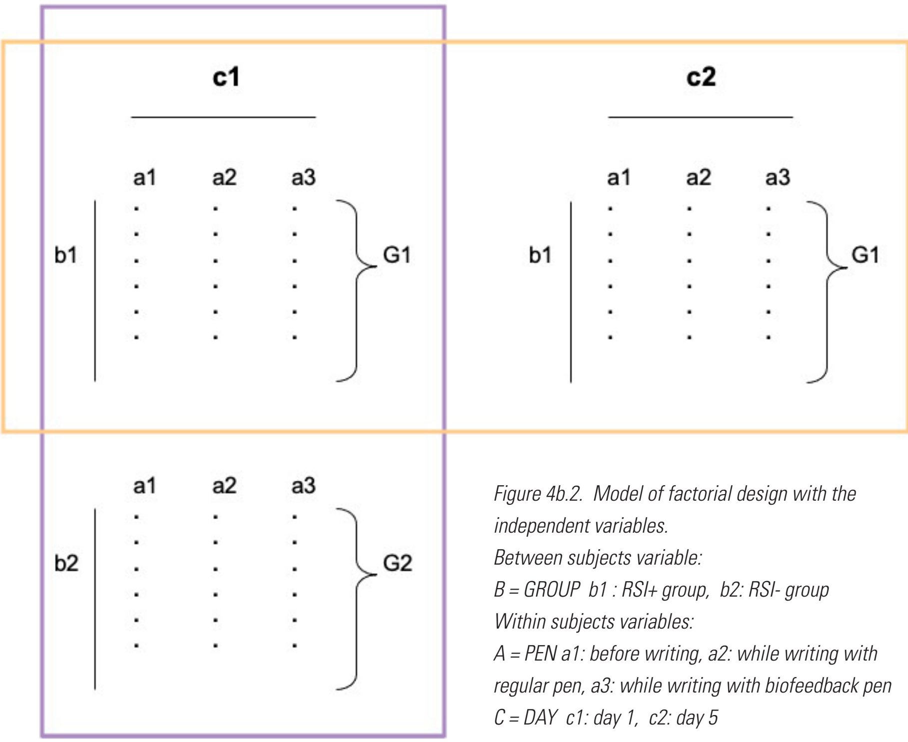


Figure 4b.2. Model of factorial design with the independent variables.
Between subjects variable:
B = GROUP b1 : RSI+ group, b2: RSI- group
Within subjects variables:
A = PEN a1: before writing, a2: while writing with regular pen, a3: while writing with biofeedback pen
C = DAY c1: day 1, c2: day 5

Research design

By means of a factorial design both individual and interactive effects of the independent variables on the dependent variable were researched. Figure 4b.2 shows the between-within subjects design with the independent variables, 2 within factors and 1 between factor.

And the dependent variables is this study were:
> The section of subclavian artery (A)
> The velocity of the blood in the subclavian artery (V)

The section of the subclavian artery can be calculated with the formula:

$$A = \frac{\pi \, . \, D_h . \, D_v}{4}$$

In which:
D_h = the measured horizontal diameter of the subclavian artery
D_v = the measured vertical diameter of the subclavian artery

The blood flow (blood volume per time unit, or velocity multiplied by the section of the blood vessel) can be calculated with the formula:

$$Q = \frac{\pi \, . \, D_h . \, D_v \, . \, L}{4 \, . \, t} = \frac{[m]^2 \, . \, [m]}{[s]} = V \, . \, A$$

In which:
Q = blood flow in the subclavian artery
D_h = the horizontal diameter of the subclavian artery
D_v = the vertical diameter of the subclavian artery
L = length of the 'tube of blood' passing per time unit
t = time
V = the measured velocity of the blood in the subclavian artery
A = calculated section of the subclavian artery

Materials

In blood velocity measurement studies often the systolic forward peak velocity or the time averaged mean velocity values are taken. In the example of the femoral arterial waveform in Figure 4b.3 both these systolic forward peak velocity (V_F) and the time averaged mean velocity V_M can be seen. The relationship between these and other parameters have been described by Holdsworth et al. [2], who investigated human carotid artery velocity waveforms and generated realistic computed blood flow waveforms. The parameters V_F and V_M (in the Holdsworth study indicated with respectively V_{MAX} and V_{CYC}) exhibited a strong positive correlation ($r = 0.66$, $p < 0.0001$). In our study the systolic forward peak velocity was measured because of practical reasons, and was used to compare velocity values amongst subjects. For reasons of accuracy, the term peak velocity will be further used in our study. Consequently, the calculated flow is also the peak flow and will be indicated accordingly in this chapter.

The peak velocity and the horizontal and vertical diameter of the subclavian artery were measured by means of echo-Doppler. The equipment used was Toshiba diagnostic ultrasound, model SSA 340A with a linear array transducer of 7.5 MHz. The probe was held in an angle of 45 degrees to the skin surface. To minimise angle-induced errors, a device was used that showed the angle in which the probe was held (Figure 4b.4). Furthermore, the probe mouth was positioned on the skin surface, within the sagittal surface of the subject's body, to minimise the chance of measuring collateral vessels or the thoracic artery [3]. Measurements were made using a normal screen with B-mode to determine the diameter and split screen with B-mode and colour imaging on the right and Doppler frequency shift on the left to measure the peak velocity. In blood vessels, the blood velocity has different values depending on where is measured in the cross-sectional area of the vessel and is also dependent on the moment of measurement within the cardiac cycle. For instance, the blood velocity is highest in the centre of the vessel during the peak of the systolic forward phase of the flow pulse and is in all phases zero at the vessel wall [4]. Our measurements were taken at the central axis of the artery and the peak velocity was established by taking the average of the systolic forward velocity peaks of two cardiac cycles.

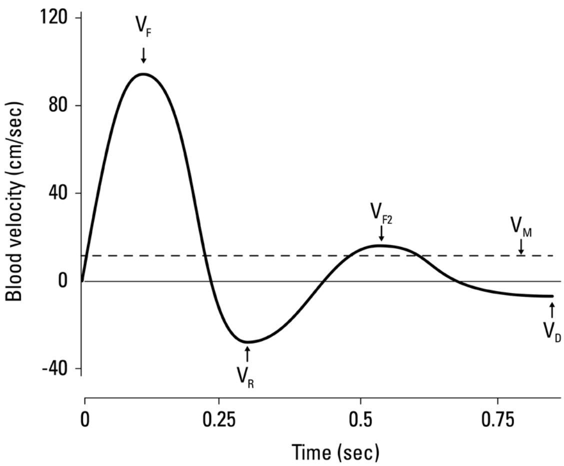


Figure 4b.3. An example of a velocity waveform and its parameters of the femoral artery. Based on Hashimoto J and Ito S, 2010 [5].
V_F = systolic forward peak velocity, V_R = reverse peak velocity, V_{F2} = diastolic forward peak velocity, V_D = end-diastolic velocity, V_M = time-averaged mean velocity.

Figure 4b.4. Blood velocity and diameter measurements in the artery subclavian performed by echo-Doppler.

An adjustable office chair and an adjustable table were available in the examination lab and were adapted to the subjects' body dimensions. Several pens with biofeedback for pinch force by means of a light signal were available for the writing exercises. Half the number of pens intentionally did not function. These were the regular pens without the feedback for pinch force. Stacks of eleven pieces of paper were available to place the writing paper on, to exclude influences on pressure by different undergrounds during the writing tasks. A questionnaire was made for the RSI+ group, related to their RSI complaints during the last week, focusing on the type, severity, frequency, duration and location of their complaints and their limitations on general daily activities. The RSI+ group completed this survey at home and took it to the research lab. A short visual analogue scale (VAS) on pain and paresthesia was developed to get an impression of the experienced complaints of the patients on the moment of research.

Procedure

The model of factorial design as shown in Figure 4b.2 gives a schematic impression of the procedure. The RSI+ group was measured during 2 different working days in one week, on Monday (DAY1) and on Friday (DAY5). The control group (RSI-) was seen only on Monday (DAY1). Baseline measurements (PEN1), measurements while writing with the regular pen (PEN2) and measurements while writing with the biofeedback pen (PEN3) were performed on both days.

DAY 1

Subjects of the RSI+ group were asked to hand in the completed questionnaire (Q1) at the beginning of day 1. Subjects of both groups were invited to sit on the office chair at the table and were helped to place the furniture in their individual ergonomically position and asked to sign an informed consent form. The RSI+ group completed also the short visual analogue scale (VAS1) for pain and paresthesia they experienced at that moment. After this, blood pressure and heart rate were assessed to anticipate on aspects of subject's general status such as stress, creating unwilling effects on blood flow.

Baseline measurements (PEN1) were made by echo-Doppler to determine the horizontal and vertical diameter of the subclavian artery and blood velocity in the subclavian artery at the location of the costoclavicular gate, see Figure 4b.4. After this, instructions for the first writing exercise were given: writing of seven prescribed identic sentences with the regular pen PEN2. During writing of the last sentence, again the horizontal and vertical diameter of the subclavian artery and the blood velocity in this artery were assessed. A five-minute rest period was introduced. Subsequently, new instructions were given to write the same seven sentences with the biofeedback pen (PEN3) with visual feedback on pinch force (Figure 4b.5). The instruction given was to ensure that the light signal at the top of the pen would not light up to minimise pinch force. While writing the seventh sentence, arterial diameter and blood velocity assessments were made for the third time. At the end of these measurements, blood pressure and heart rate were determined again. At that time, the tests for the subjects of the RSI- group were completed.

Figure 4b.5. One of the subjects writing with the biofeedback pen attempting not to light up the light signal at the top of the pen in order to minimise pinch force.

Midweek

From Tuesday till Thursday of the same week, the subject of the RSI+ group participated in writing exercises, three times a day, under supervision of the examiners in the lab. They consisted of writing and drawing with the biofeedback pen, while making sure the signal did not light up. In this way they could adopt to the more relaxed way of writing.

DAY 5

After these three days, the RSI+ group performed a similar measurement protocol on Friday (DAY5) as they did on the first day, Monday. At the beginning of day 5 the RSI+ group completed again the short visual analogue scale (VAS2) for pain and paresthesia they experienced at that moment. At the end of day 5 the questionnaire (Q2) regarding the subject's RSI complaints during the past week (the week of exercising with the biofeedback pen) was again completed by the participants of the RSI+ group to investigate possible self-reported effects of the intervention.

Additional week

After this week of performing writing exercises in the laboratory, the RSI+ group was asked to write another week regularly with the biofeedback pen during their own activities at home, at work or study. They were given the instruction to write the way they had learned during the foregoing week. At the end of this second week they were asked to fill out (for the third and last time) the questionnaire (Q3), which would give an impression about possible effects by their own use of the biofeedback pen.

Statistical analyses

By means of a factorial design the effects (both individual and interactive) of the independent variables on the dependent variables were researched.
The selected analysis for this was General Linear Model – Repeated measures.
Within subject's factors were tested with Wilks' Lambda in a MANOVA.
The post hoc between subject's factors were tested in ANOVA's and difference contrast analyses (SPSSStatistics 25.0.0). The visual analogue scales and the questionnaires were compared using a paired samples t-test. For all statistical analyses the level of significancy was set at $p < 0.05$.

> RESULTS

DAY1, RSI+/RSI-

The results for the dependent variables, section and peak velocity, and consequently the peak blood flow regarding both groups RSI+ and RSI- at day 1 are presented first.

Peak velocity of the blood in the subclavian artery (DAY1, RSI+ / RSI-)

Figure 4b.6 presents the main effects of the General Linear model and post hoc results of the peak velocity of the blood in the subclavian artery of both groups RSI+ and RSI- at day 1. It can be readily seen that the RSI+ group has a lower peak velocity in the subclavian artery than the RSI- group over all three pen conditions. Additionally, it seems that peak velocity in pen condition 3 (writing with the biofeedback pen) is lower than in pen condition 2 (writing with the regular pen) for both RSI+ and RSI- groups. The between-within subject analysis with General Linear Model revealed a main significant effect between the RSI- and RSI+ group for peak velocity with a significantly {$F(1,35) = 5.73$, $p = .022$}. The main effect of the within factor PEN was significant using MANOVA Wilks' Lambda (.83) $F(2,34) = 3.57$, $p = .039$. No interaction effects were found. Post hoc analysis with a difference contrast only revealed a significant difference between pen condition 3 versus condition 2,

{$F(1,35) = 5.16, p = .029$}. Post hoc analysis (ANOVA) between the groups RSI+ and RSI- in pen condition 3 (writing with the biofeedback pen) showed a significant effect, indicating a lower peak velocity in the RSI+ group as compared to the RSI- group in this condition. Group comparisons in the other two pen conditions were not significant. The ANOVA results are considered less important because no interaction effects were found in the General Linear Model.

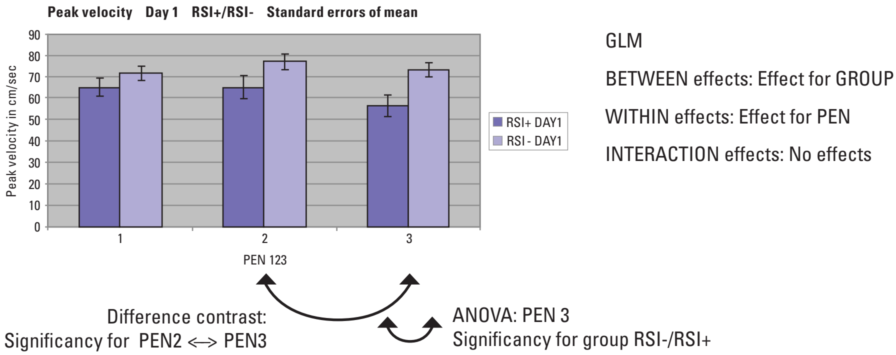


Figure 4b.6. Peak velocity of the blood in the subclavian artery at day 1 for both groups RSI+ and RSI-. Results of the General Linear Model on the right and the post hoc results at the bottom.
PEN1 = baseline (number 1 on the horizontal axis of the bar chart),
PEN2 = writing with regular pen (number 2 on the horizontal axis of the bar chart),
PEN3 = writing with biofeedback pen (number 3 on the horizontal axis of the bar chart).

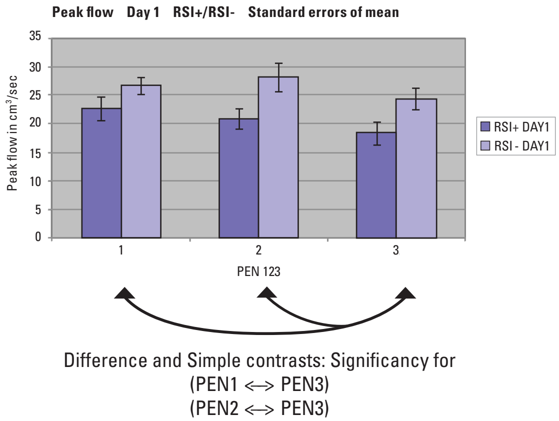
Section of the subclavian artery (DAY1, RSI+/RSI-)

Figure 4b.7 shows the main effects of the General Linear model and related post hoc results of the section of the subclavian artery for both groups RSI+ and RSI- at day 1. The results of the General Linear Model indicate that there are no main effects for the between factor GROUP (RSI+, RSI-) nor for the within factor PEN (PEN1, PEN2, PEN3). No interaction effects were found either.

Figure 4b.7. Section of the subclavian artery at day 1 for both groups RSI+ and RSI-. Results of the General Linear Model on the right and the post hoc results at the bottom.
PEN1 = baseline, PEN2 = writing with regular pen, PEN3 = writing with biofeedback pen.

Peak flow of the blood in the subclavian artery (DAY1, RSI+/RSI-)

Figure 4b.8 presents the main effects of the General Linear model and related post hoc results of the peak flow of the blood in the subclavian artery of both groups RSI+ and RSI- at day 1. The RSI+ group has a lower peak flow in the subclavian artery than the RSI- group over all pen conditions. In addition, it seems for both RSI+ and RSI- groups that the peak flow in pen condition 3 is lower than in pen condition 2, and that peak flow in pen condition 3 is also lower than in pen condition 1. The between-within subject analysis with General Linear Model showed a main significant effect between the RSI- and RSI+ group for peak flow with a significantly {$F(1,35) = 4.75$, $p = .036$}. The main effect of the within factor PEN was significant using MANOVA Wilks' Lambda (.82) $F(2,34) = 3.79$, $p = .033$. No interaction effects were found. Post hoc analysis with a difference contrast revealed a significant difference between pen condition 3 versus condition 2, {$F(1,35) = 7.40$, $p = .010$}. Post hoc analysis with a simple contrast revealed a significant difference between pen condition 3 versus pen condition 1, {$F(1,35) = 6.93$, $p = .013$}. Post hoc analysis (ANOVA) between the RSI+ and RSI- groups in the three pen conditions showed no significant effects.



GLM

BETWEEN effects: Effect for GROUP

WITHIN effects: Effect for PEN

INTERACTION effects: No effects

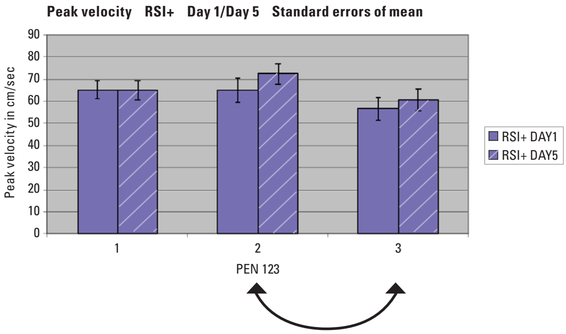
Figure 4b.8. Peak flow of the blood in the subclavian artery at day 1 for both groups RSI+ and RSI-. Results of the General Linear Model on the right and the post hoc results at the bottom. PEN1 = baseline, PEN2 = writing with regular pen, PEN3 = writing with biofeedback pen.

DAY1/DAY5, RSI+

The RSI+ group was measured again after a week of exercising with the biofeedback pen. The results for the dependent variables, section and velocity, and consequently the blood flow are presented.

Peak velocity of the blood in the subclavian artery (RSI+, DAY1/DAY5)

Figure 4b.9 presents the main effects of the General Linear model and post hoc results of the peak velocity of the blood in the subclavian artery of the RSI+ group at day 1 and day 5. The peak velocity in the subclavian artery over the three pen conditions at day 1 seems almost equal or lower than at day 5. In addition, it seems for both day 1 and day 5 that peak velocity in pen condition 3 is lower than in pen condition 2. The between-within subject analysis with General Linear Model showed no main effect for the within factor DAY. The main effect of the within factor PEN was significant using MANOVA Wilks' Lambda (.21) $F(2,10) = 18.97$, $p < .001$). No interaction effects were found. Post hoc analysis with a difference contrast revealed a significant difference between pen condition 3 versus condition 2, {$F(1,11) = 21.87$, $p = .001$}.



GLM

WITHIN effects: No effect for DAY

WITHIN effects: Effect for PEN

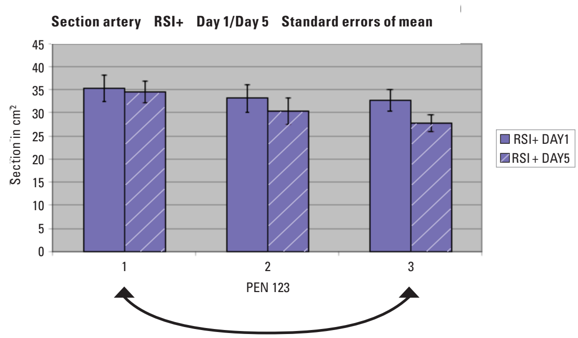
INTERACTION effects: No effects

Difference contrast: Significancy for PEN2 <--> PEN3

Figure 4b.9. Peak velocity of the blood in the subclavian artery at day 1 and day 5 for the RSI+ group. Results of the General Linear Model on the right and the post hoc results at the bottom. PEN1 = baseline, PEN2 = writing with regular pen, PEN3 = writing with biofeedback pen

Section of the subclavian artery (RSI+, DAY1/DAY5)

Figure 4b.10 presents the main effects of the General Linear model and post hoc results of the section of the subclavian artery of the RSI+ group at day 1 and day 5. The section of the subclavian artery over the three pen conditions at day 1 seems almost equal or higher than at day 5. In addition, it seems for both day 1 and day 5 that the arterial section in pen condition 3 is smaller than in pen condition 1. The between-within subject analysis with General Linear Model showed no main effect for the within factor DAY. The main effect of the within factor PEN was significant using MANOVA Wilks' Lambda (.54) $F(2,10) = 4.34$, $p = .044$. No interaction effects were found. Post hoc analysis with a simple contrast revealed a significant difference between pen condition 3 versus condition 1, {$F(1,11) = 9.53$, $p = .010$}.



GLM

WITHIN effects: No effect for DAY

WITHIN effects: Effect for PEN

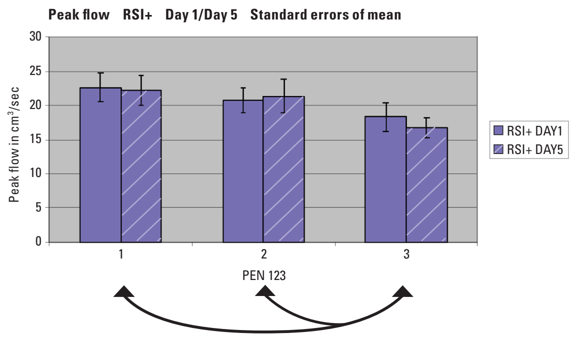
INTERACTION effects: No effects

Simple contrast: Significancy for PEN1 <-> PEN3

Figure 4b.10. Section of the subclavian artery at day 1 and day 5 for the RSI+ group. Results of the General Linear Model on the right and the post hoc results at the bottom. PEN1 = base line, PEN2 = writing with regular pen, PEN3 = writing with biofeedback pen.

Peak flow of the blood in the subclavian artery (RSI+, DAY1/DAY5)

Figure 4b.11 presents the main effects of the General Linear model and post hoc results of the peak flow of the blood in the subclavian artery of the RSI+ group at day 1 and day 5. The difference between the peak flow of the subclavian artery at day 1 as compared to the peak flow of the subclavian artery at day 5 seems to vary over the three pen conditions. In addition, it seems for both day 1 and day 5 that the peak flow in pen condition 3 is lower than in pen condition 2 and also lower than in pen condition 1. The between-within subject analysis with General Linear Model showed no main effect for the within factor DAY. The main effect of the within factor PEN was significant using MANOVA Wilks' Lambda (.22) $F(2,10) = 17.88$, $p < .001$. No interaction effects were found. Post hoc analysis with a difference contrast revealed a significant difference between pen condition 3 versus condition 2 {$F(1,11) = 21.76$, $p = .001$}. Post hoc analysis with a simple contrast revealed a significant difference between pen condition 3 versus condition 1, {$F(1,11) = 36.84$, $p < .001$}.



GLM

WITHIN effects: No effect for DAY

WITHIN effects: Effect for PEN

INTERACTION effects: No effects

Difference and Simple contrasts: Significancy for
PEN1 <-> PEN3
PEN2 <-> PEN3

Figure 4b.11. Peak flow of the blood in the subclavian artery at day 1 and day 5 for the RSI+ group. Results of the General Linear Model on the right and the post hoc results at the bottom. PEN1 = base line, PEN2 = writing with regular pen, PEN3 = writing with biofeedback pen

Questionnaires and VAS scales

The paired t-tests indicated no differences (in severity, frequency, duration of subject's complaints and their limitations on general daily activities) by the questionnaires when comparing baseline values, values after the first week of supervised writing with the biofeedback pen and values after the second week of independent writing with the biofeedback pen. Also a similar comparison between day 1 and day 5 on pain and paresthesia by the visual analogue scales showed no significant differences.

> DISCUSSION

In this discussion we present the key findings, evaluate the results in light of the alternative explanation for the reduced blood flow as introduced in the introduction of this chapter and answer the research questions posed.

DAY1, RSI+/RSI-

The *peak velocity* measured in the subclavian artery of healthy subjects (RSI-) was higher than in subjects with RSI (RSI+) over the three pen conditions. No interaction effects were found (between GROUP and PEN). For both groups (RSI- and RSI+) the peak velocity was higher in writing with the regular pen (PEN2) as compared to writing with the biofeedback pen (PEN3).

In writing with the biofeedback pen (PEN3), the peak velocity was significantly higher in the healthy subjects as compared to the RSI+ group. At baseline (PEN1) and when writing with the regular pen (PEN2) this difference was not found.

Figure 4b.12 shows the schematic blood velocity before, in and after a constricted vascular area. Because the same volume of blood per time unit is passing through the constricted area as through the non-constricted area before and after the constriction, a higher blood velocity can be expected in the constriction. For this reason we expected a higher peak velocity in the costoclavicular gate of the RSI+ group as compared to the RSI- group. However, the results show the contrary, the peak velocity in the RSI- group was higher than in the RSI+ group.

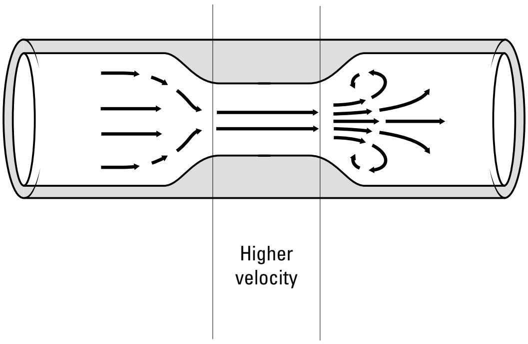


Figure 4b.12. Increased fluid velocity in a constricted vascular area. Based on Zierler RE and Sumner DS, 2014 [4]

The established higher peak velocity for both groups in writing with the regular pen (PEN2) as compared to writing with the biofeedback pen (PEN3) was expected because of the assumed narrowed gate in pen condition 2. However, we expected to see the biofeedback pen having more effect on the RSI+ group than on the healthy controls. The absence of interaction effects (between GROUP and PEN) didn't confirm this.

Post hoc analysis indicated a difference in peak velocity between the RSI+ and RSI- group in writing with the biofeedback pen (PEN3). In particular in this pen condition 3 this difference was not expected. As shown in Figure 4b.1, the constriction of the artery would have been cleared in the condition of writing with the biofeedback pen and would have resulted in equalised velocity levels.

For the *section* the arterial vessel no differences were found between the RSI+ group and the RSI- group, nor between the pen conditions (PEN1, PEN2, PEN3). No interaction effects (between the factors GROUP and PEN) were found as well.

Because the alternative explanation is based on an assumed constricted subclavian artery in the RSI+ group (Figure 4b.1), it is unexpected that we didn't find a difference between both groups for the arterial section. And because of the assumed relaxing effect of the biofeedback pen, we expected in the RSI+ group a larger section in pen condition 3 (PEN3) as compared to writing with the regular pen (PEN2) and the baseline pen condition (PEN1). However, these assumptions were not confirmed.

The *peak flow* in healthy subjects (RSI-) was higher than in RSI+ subjects over all pen conditions. No interaction effects were found (between GROUP and PEN). The peak flow when writing with the biofeedback pen (PEN3) was lower as compared to writing with the regular pen (PEN2) and also lower as compared to baseline (PEN1).

The higher peak flow in healthy subjects compared to subjects with RSI corresponds well with the alternative explanation concerning reduced blood flow in people with RSI complaints. Healthy subjects are supposed to have no or less constriction and therefore a higher peak flow in their circulatory system of the upper limbs is expected (see Figure 4b.13). However, the lowest peak flow for both RSI- and RSI+ groups in the condition of the biofeedback pen (PEN3) as compared to the other conditions was against expectations. We expected an increased over all circulatory blood flow in writing with the biofeedback pen (PEN3) as compared to pen conditions 2 and 1, because of the assumed cleared arterial restriction in condition 3. We also expected interaction effects assuming the biofeedback pen having more effect on the RSI+ group than on the healthy controls. However, this was not confirmed.

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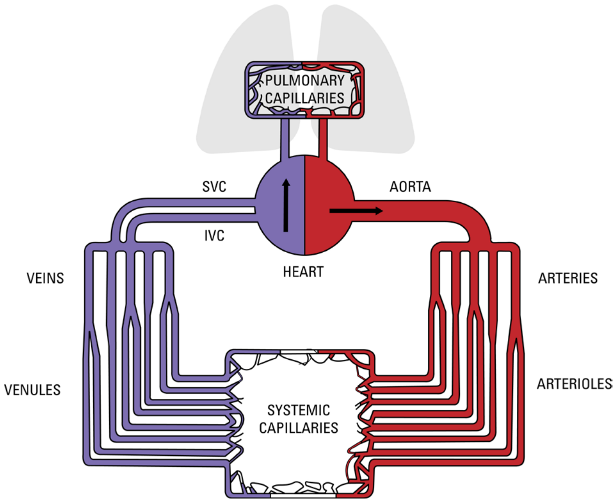

Figure 4b.13. The circulatory system (schematic):
Purple = deoxygenated blood
Red = oxygenated blood
SVC = superior vena cava
IVC = inferior vena cava
Through these both veins the blood returns to the heart (from the upper and lower parts of the body respectively).

DAY1/DAY5, RSI+

No difference was found between the *peak velocity* measured at day 1 and day 5 in the subclavian artery of subjects with RSI (RSI+) over the three pen conditions. No interaction effects were found (between DAY and PEN). For both days the peak velocity was higher in writing with the regular pen (PEN2) as compared to writing with the biofeedback pen (PEN3).

Due to the absence of this difference in *peak velocity* at DAY1 and DAY5, it seems that there was no 'learning effect' after multiple days of exercising with the biofeedback pen on the subjects' ability to relax the neck muscles during the three pen conditions. It was expected that the longer exercising period at DAY5 would have resulted in lower peak velocity levels in the costoclavicular gate because of a reduced or eliminated constriction.

For both DAY1 and DAY5 the *peak velocity* when writing with the regular pen (PEN2) was higher than when writing with the biofeedback pen (PEN3) which would indicate a narrowed gate still at both days. However, it was expected that writing with the regular pen (PEN2) at DAY5 would have resulted in a more reduced or eliminated constriction (see Figure 4b.14) and consequently reduced velocity as compared to DAY1 because of the learned relaxation while writing. These post hoc results and the absence of interaction effects didn't confirm this.

Also for the arterial *section* no differences were found between DAY1 and DAY5 in the RSI+ group over the three pen conditions. And no interaction effects (between GROUP and PEN) were found as well. For both DAY1 and DAY5 the section when writing with the biofeedback pen (PEN3) was smaller as compared to the section when writing with the regular pen (PEN2).

This indicates that also in these section results, no 'learning effect' could be identified after multiple days of using the biofeedback pen. The smaller arterial section found in PEN3 compared to the baseline values (PEN1) for both DAY1 and DAY5 was not according to the expectations.

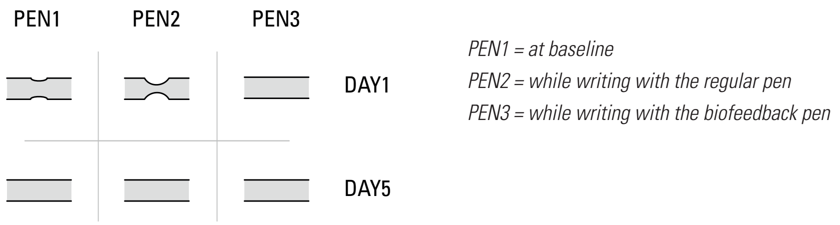

Figure 4b.14. Hypothetical representation of the subclavian artery and constriction of people with RSI (the RSI+ group, investigated at day 1 and day 5 in this study) according to the alternative explanation for blood flow reduction.

In the calculated arterial *peak flow* of the RSI+ group over the three pen conditions no difference was also established between DAY1 and DAY5. No interaction effects (between DAY and PEN) were found in these results either. For both DAY1 and DAY5, the peak flow when writing with the biofeedback pen (PEN3) was lower compared to writing with the regular pen (PEN2) and also lower when compared to baseline (PEN1).

Also in the results of the calculated peak flow, the former mentioned 'learning effect' of longer use of the biofeedback pen could not be established. In addition, these results indicate that both short (DAY1) and longer (DAY5) writing with the biofeedback pen did not increase the arterial peak flow as was expected.

The results of the *visual analogue scales* on pain and paresthesia and the *questionnaires* related to RSI complaints and limitations on general daily activities showed no improvement with regard to the complaints in the RSI+ group after the week of writing in the laboratory condition and also not after the week of independent use of the biofeedback pen.

> REFLECTION

The lower blood flow levels in the upper extremities of people with RSI complaints compared to healthy controls found in our study are in agreement with the alternative explanation as introduced in the introduction of this chapter. Previous studies on blood flow of Brunnekreef [6, 7, 8] found reduced blood flow values in the upper limbs of subjects with RSI as well. However, the body regions of research in these studies were the more distal parts of the extremities, whereas we focused on the upper arm-shoulder region at the location of the costoclavicular gate.

The effects found - and not found - in our study of writing with the two different pens on the blood flow of subjects with and without RSI are more difficult to explain. The isolated finding of a higher peak velocity for both (RSI+ and RSI-) groups in writing with the regular pen (PEN2) as compared to writing with the biofeedback pen (PEN3) could be consistent with the explanation of a constricted costoclavicular gate in pen condition 2. However, the assumed constriction (Figure 1) was not supported by our findings related to the arterial section where no differences were found between the three pen conditions. Also, peak blood velocity values in the costoclavicular gate didn't indicate an arterial restriction in subjects with RSI since the peak velocity values in the healthy controls were unexpectedly higher than in the RSI+ group. Moreover, we didn't find the expected differences in arterial section as presented in Figure 1 between both groups. The peak blood flow of both (RSI+ and RSI-) groups was expected to increase during writing with the biofeedback pen (PEN3). However, our blood flow results showed the opposite and did not confirm that an arterial constriction was reduced or eliminated using the pen with biofeedback.

Furthermore, it was unexpected not to find interaction effects. A stronger effect of the pen conditions (baseline, writing with the regular pen, and writing with the biofeedback pen) on the section, peak velocity and resulting peak flow in the RSI+ group compared to the healthy group was expected, due to the assumed constricted subclavian artery of this group in pen condition 1, the further narrowing under the task stress of pen condition 2 and the widening by writing with less pinch force in pen condition 3.

Based on the results of the section, peak velocity and peak blood flow after writing with the biofeedback pen for several days, no 'learning effects' could be determined. The expected vascular normalisation due to reduction of pinch force and consequently muscular tension in the arm, shoulder and neck muscles was not established in our study.

Also the self-reported results didn't show relief of complaints after a week of exercising with the biofeedback pen nor after the extra week of independent usage of the pen. Although the absence of the light during the writing task with the biofeedback pen gave certainty regarding the reduced pinch force, the duration of our training could still have been too short to have effect on the muscle tension through the upper limbs and consequently on the vascular normalisation. Other studies of successful interventions including biofeedback like Peper et al. [9] showed a reduction in computer work related body symptoms after a 6 weeks intervention.

> LIMITATIONS OF THE STUDY

This study also has its limitations, like the mentioned fact that the intervention lasted only two weeks. Other points of attention are that the measurements were taken in the costoclavicular gate which is a difficult location to measure because of the proximity of several bones, arterial veins and natural movements due to breathing. There may also have been some turbulence in the circulation that may have influenced our velocity measurements. However, the differences in blood flow found between the complaints group and the non-complaints group are in agreement with previous studies which gives confidence in the measurements performed. Furthermore, we can question whether our measurements were taken exactly in the costoclavicular gate or maybe somewhat below. If this had been the case, there would still have been increased blood flow after writing with the biofeedback pen, which we have not been able to determine.

For practical reasons the choice was made to measure the forward systolic peak velocity and not the mean velocity of the subjects' cardiac cycles. As indicated, there is a strong positive correlation between these two variables. However, it could be that the results based on the mean velocity over the cardiac cycle would differ from those found in our study. And we applied another simplification to the blood velocity measurements. As described in the section 'Materials' of the 'Methods' paragraph, blood velocity is not the same everywhere across the cross sectional area of the arterial vessel and this velocity profile is also dependent on the dynamics of the flow field, that is, the moment of measurement within the cardiac cycle. The Holdsworth study [2] demonstrated how these velocity profiles under pulsatile flow conditions can be computed based on Womersley's analytic solution. As indicated, we recorded at the moment and location where velocity is highest, in the centre of the subclavian artery during the peak of the systolic forward phase. Based on this peak velocity, we calculated the forward systolic peak flow according to the formulas presented in the section 'Research design' of the 'Methods' paragraph, assuming an evenly distributed blood velocity across the cross-sectional area, by straightforward multiplying this peak velocity by the cross sectional area. We should be aware that the reported flow levels in this study are the maximum cardiac cycle flow values (Qmax), and might be overestimated by the fact that these changing velocity profiles under pulsatile flow conditions were not taken into account. However, the aforementioned simplifications were justified because in our study we only wanted to investigate differences in blood velocity and blood flow levels between groups and under different pen conditions, and the simplification was structurally applied across all measurements. The other measured variable, the section, in which the expected effects were also not found, was measured in an customary and unambiguous manner.

> CONCLUSION

This study showed a lower subclavian arterial peak velocity in subjects with RSI complaints compared to complaints-free subjects. No significant effects on the cross-sectional area of the subclavian artery in the costoclavicular gate were found by the intervention with a biofeedback pen. Peak blood flow values in the subclavian artery were established based on the measured peak velocity. The peak blood flow values were reduced during the intervention. Both these sectional and blood flow results were unexpected because the assumption was that the biofeedback pen, providing the user visual feedback on its pinch force, would stimulate the participants to reduce muscle tension all the way to the neck muscles, widening the costoclavicular gate and increase the blood flow. In our study, we were unable to demonstrate the expected effect of the biofeedback pen. It is possible that the results would be different with a longer duration of the intervention.

> ACKNOWLEDGEMENT

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CHAPTER 5

NEW PRODUCT IDEAS TO SUPPORT MACRO BREAKS IN COMPUTER WORK

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> ABSTRACT

A healthy work-to-rest ratio during computer work can be an important part of successful preventive work-related upper limb disorders (WRULD) intervention. Existing break software applications designed to realise such a work-to-rest ratio often possess product features that limit their functionality. Most applications focus on physical relaxation by implementing (micro) breaks into computer work time. Through the emphasis on break time, these applications give the impression that there is no productivity, possibly strengthened by the applications themselves that often visualise the remainder of the break as a slowly decreasing time bar. Moreover, application features such as blocking input devices may counteract cognitive relaxation of computer workers. As imposed physical breaks can be cognitively stressful, especially when deadlines loom, combining physical and cognitive relaxation is a challenge. Actually, research shows that, instead of micro breaks, ensuring users take macro breaks needs more attention. It is worthwhile to think of new products for both forms of relaxation within this time span. An idea for a possible product innovation is tested with a small sample and is presented here: a new software application that shows customisable video content during macro breaks.

Keywords: cognitive relaxation, computer work, macro breaks, product innovation, repetitive strain injuries (RSI), work-related upper extremity musculoskeletal disorders (WRUEMD), work-related upper limb disorders (WRULD), work-to-rest ratio.

> INTRODUCTION

Throughout the last decades, numerous terms were used to indicate discomfort and pain symptoms in the arm, neck and shoulder region, such as Repetitive Strain Injuries (RSI), Cumulative Trauma Disorders (CTD), Occupational Overuse Syndrome (OOS), and Work-Related Upper Extremity Musculoskeletal Disorders (WRUEMD) or Work-Related Upper Limb Disorders (WRULD). More recently, the focus has shifted towards plain designations just indicating the troubled physical area, such as Complaints of Arms, Neck and/or Shoulder (CANS), "neck-shoulder pain", or "arm-hand pain". The rationale for this shift is that often no specific medical disorder or injury can be diagnosed, and the development of the complaints and the conditions in which they occur can differ strongly. Nevertheless, there is consensus on the nature of the complaints. They are characterised by a feeling of pain, stiffness, tingling, clumsiness, loss of coordination, loss of strength, skin colouring and skin temperature differences [1]. There is also consensus on the multifactorial nature of this syndrome's origin [2]. The most prominent risk factors mentioned in literature are of a physical nature, like repeated movements, static postures, awkward body positions, high forces, and high precision. Besides physical risk factors, psychosocial risk factors such as stress and high job demands, as well as personality traits like overcommitment and perfectionism, have been reported to be associated with these problems [3-5]. This large variety of symptoms and risk factors suggests that there is not just one mechanism that explains the development of the complaints, but that several mechanisms may act simultaneously [6]. Because the abovementioned terms are either incorrect or incomplete in the sense that they do not cover the syndrome's etiology, the internationally most commonly used and recognised term WRULD will be used in this paper.

One of the most frequently recommended WRULD interventions is the introduction of more rest breaks, to interrupt computer workers' physical and mental loading patterns. According to Blatter et al. [7], improving work-to-rest ratios, possibly supported by break software, is the most promising preventive measure for WRULD problems related to computer work. These authors base their statement on pathophysiological and etiological plausibility, and conclude that high quality research on the effectiveness of such measures is absent and therefore necessary.

Not only health aspects should be taken into consideration. According to Dul et al. [8], high quality ergonomic systems should optimize both human well-being (including health) and overall system performance (including productivity), and these aspects influence each other in the short and the long term [8].

Legislation, standards and recommendations related to rest breaks in computer work

In European countries, the employer has legal responsibilities with regard to work-to-rest ratios in computer work. These are stated in Council Directive 90/270/EEC [9] on the minimum safety and health requirements for work with display screen equipment. Article 7 on daily work routine declares: "The employer must plan the worker's activities in such a way that daily work on a display screen is periodically interrupted by breaks or changes of activity reducing the workload at the display screen." There is a relatively wide margin for interpreting this directive. In the United States, the Occupational Safety and Health Act of 1970 requires employers to comply with hazard-specific safety and health standards as issued and enforced by either the Department of Labor's Federal Occupational Safety and Health Administration (OSHA), or an OSHA-approved State Plan. The General Duty Clause in this act requires employers to provide their employees with a workplace free from recognized hazards likely to cause death or serious physical harm. Until now, OSHA has issued no specific required standards for the design of office environments, computer workstations or related users' working patterns. Nevertheless, OSHA aims to inform employers and employees about potential hazards and interventions that employers can use to prevent or reduce the potentially harmful effects of working with computers. OSHA maintains a Web-based 'eTool' [10] on computer workstations in which the following recommendation under 'Micro breaks or rest pauses' is made: "Build short micro pauses into computer use sessions. Frequent short breaks are desirable. Every hour, take a five-minute break from computer tasks. Look away, stretch, get up, or walk. These brief pauses provide time for muscles and tendons to recover." And under 'Task Rotation or Job Enlargement': "If you must perform a variety of tasks, when possible, intersperse them throughout the work day. Minimize long blocks of uninterrupted computer time by doing other non-computer tasks such as photocopying, phone work, cleanup, etc."

Generally, workers have the right to take breaks, but whether or not they are paid for depends on the type of interruption and the terms of their employment contract. We can distinguish between:

1. holidays, typically a number of days off in a row,
2. 'daily rest' and 'weekly rest', the break between finishing one day's work and starting the next day (overnight), and between finishing one week's work and starting the next (weekend),
3. rest breaks, like lunch, coffee, or tea breaks,
4. unplanned interruptions of work, such as a breakdown of equipment, inappropriate design of work, or even fire drills,
5. short rest breaks or pauses.

The first and third types of interruptions are often paid, but do not have to be unless stated in the contract. The second type of break is almost never paid. The fourth type is usually paid work time, and so are the type 5 short rest breaks or pauses taken unconsciously or intentionally by the employee. The duration of this last type of interruptions is in the order of seconds (micro breaks), or minutes (macro breaks), and these are the main focus in the following paragraphs.

> LITERATURE REVIEW AND DESIGN OPPORTUNITIES

Approach

A literature study was performed on the effectiveness of rest breaks, physical exercises, and existing break software applications. Based on these outcomes, design opportunities were formulated for the subsequent product idea development. Consequently, two product ideas were created reflecting these insights. One of these ideas was subject of a small user test and is presented in more detail.

Effectiveness of existing break software applications

Many break software applications, introducing artificial micro and macro breaks into the user's computer work time, were launched with the aim to prevent or reduce musculoskeletal disorders like WRULD. Some applications offer the user possibilities to engage in physical exercises during the breaks. However, the effectiveness of pauses and exercises during computer work has not been defined unambiguously in scientific literature. An examination of the available literature by Mathiassen [11] showed that the effectiveness of more rest breaks and physical variation in jobs with long-lasting low-level loads, or repetitive movements on musculoskeletal disorders is weakly supported by empirical evidence. In a study by Van den Heuvel [12] more specifically, the effects of a software program stimulating (micro and macro) breaks and physical exercises on the recovery from neck and upper limb symptoms among computer workers were evaluated. No effects on self-reported severity and frequency of the symptoms were observed when comparing the pre- and post-intervention scores. Additionally, no effects on self-reported sick leave were found. However, subjects retrospectively reported 'perceived recovery' from their complaints more often than a control group without intervention. There seemed to be no additional effect from performing physical exercises during the breaks. Considering the impact of additional breaks on discomfort rather than on complaints, McLean et al. [13] investigated the effect of break-software-induced micro breaks (30 seconds at 20 minute intervals, 40 minute intervals, and at participants' own discretion) in the daily routine of female workers performing keying and data entry tasks. They found beneficial effects of micro breaks on subjective discomfort ratings in the neck, the low back, the shoulder, and the forearm/wrist areas, particularly when breaks were taken at 20 minute intervals. Similarly, Galinsky et al. [14] found relatively small but significant reductions in data-entry workers' discomfort when adding macro breaks (four times 5 minutes per day) to their daily programme. Supplementary breaks attenuated accumulation of discomfort during work sessions (most markedly in the back, neck, and dominant shoulder/upper arm regions). No effects of physical exercises (stretching) during breaks on discomfort were observed. Overall mean ratings of discomfort were relatively low, and mean reductions in discomfort produced by the effects of the rest breaks were rather small. Considering these studies, an important open question remains whether these relatively modest effects of rest breaks on discomfort will, in the long term, have positive effects on the prevention or reduction of actual WRULD complaints.

Design opportunities

During the second author's master thesis project, two design opportunities – theoretically fruitful directions to pursue - were defined based on literature and users' experiences with existing break software.

Design opportunity 1: Aiming for cognitive relaxation

Mac Lean et al. [13] indicated that if breaks are regimented in computer work, this might result in added stress due to work interruption. In a study by Henning et al. [15], particularly more complicated (less repetitive) VDU operations of computer workers seemed to be susceptible to disruptions of administered rest breaks. Computer workers were found reluctant to comply with scheduled short (3 sec and 3 min) rest breaks because of an increased risk of errors or the need to repeat processing steps. Worker self-management of discretionary rest break behaviour (discretional rest breaks with feedback on their rest break behaviour) was proposed in order to improve the integration of the break system with the working tasks. Henning et al. stated that as computer-mediated work becomes more complex and less repetitive, the importance of integrating short rest breaks with task demands will probably increase since scheduled rest breaks will seriously disrupt these tasks. It can be confirmed that in academic work environments like the Faculty of Industrial Design Engineering at Delft University of Technology [16, 17] or at Wageningen University in the Netherlands [18], the acceptance of existing pause software is rather low. An important reason is that the focus of most break software applications is mainly on physical relaxation while the aforementioned cognitive aspects receive little attention. One example of a cognitively stressful feature is the enforcement of advised breaks on the users, sometimes even by blocking the input devices.

Former studies [19] have shown that computer workers regard unexpectedly long computer response times in combination with computer dependence as an important stress factor. Other adverse features are the displayed remainders of a break, dedicated to physical recovery but creating a cognitive waiting experience. This feedback emphasises temporary inactivity and thus decreased productivity, which induces mental stress especially when a deadline is near; the available time reduces while the amount of work tasks stays the same. The performance of a computer task in combination with exposure to a cognitive stressor can induce (physical) muscular tension [20]. Moreover, there is general agreement on the relationship between extensive muscular tension and the occurrence of WRULD complaints. These connections underline the importance of cognitive relaxation during breaks.

Nevertheless, it is not easy to create cognitive relaxation, for example when users 'just want to finish something'. It is particularly difficult because of human's inability to successfully 'shut down' from mental stress, meaning that these stress levels stay high during breaks [21]. Mental workload and cognitive problems are of a complex nature, more difficult to measure and to provide efficient solutions to, and are more seldom studied or solved in comparison to physical problems in computer-supported work [22]. The realisation of cognitive relaxation during breaks, even though the user has deadlines to meet, presents both possibilities and challenges for future preventive measures.

Design opportunity 2: Focusing on macro breaks

Regardless of the ongoing debate on possible health benefits of existing break software as discussed in the paragraph 'Effectiveness of existing break software applications', there is some doubt whether these applications are actually able to significantly alter a worker's work-to-rest schedule in itself. Slijper et al. [23] examined the differences in number and timing between natural work-pause patterns of twenty healthy computer users, and their pause patterns when pause regimes, available in a Dutch break software application, were imposed. The participants had computer-intensive jobs – an estimated 5.5 (±1.1) hours per day – in the academic hospital of Rotterdam, the Netherlands. Most of the participants had administrative jobs, were researchers, or had managerial functions. The related time traces were recorded during their computer work, which consisted mainly of text processing, email and Internet tasks. In this study, computer use was referred to as making mouse movements, mouse clicks, mouse wheel use, or keyboard strokes. The obtained time traces in between these events were used to calculate pause distribution.

According to this study by Slijper and colleagues [23], the vast majority (96%) of natural pauses were found to be shorter than one second, and only a small number of pauses had long durations. The distribution of pauses was extremely skewed; pauses with twice the duration were approximately twice less likely to occur. In order to examine how the workers' computer use patterns would be altered by the influence of the six least stringent pause regimes of the aforementioned application, a simulation of this software was performed on the recorded time traces. The authors found that the more stringent a regime becomes, the more pauses are administered, and that the majority (89%) of the administered pauses were micro breaks. On average, 38 micro pauses of five to ten seconds compared to only four macro breaks with durations of five to eight minutes were inserted on a daily basis. Also, the number and timing of pauses with similar time lengths before and after the implementation of the software were compared. In the recorded files, on average 25% micro breaks were imposed artificially on top of the spontaneously taken micro breaks. With regard to the macro breaks, on average 57% were inserted additionally to the naturally taken macro breaks. The authors concluded that the number of pauses given on top of the ones that occur naturally is rather small, especially with the micro breaks. With regard to the timing of the administered pauses, the authors found that, specifically for the micro breaks, a large number of spontaneous pauses were taken just before and after the inserted ones. The spontaneous pauses occurred on average within 90 seconds. In contrast, for macro breaks the software administered a pause long before the computer user would take a break spontaneously (on average 53 minutes earlier). An important conclusion by the authors [23] is that the administration of micro pauses by the break software does not lead to a considerable change in the work-pause pattern of computer users. Contrary to that, the administration of macro pauses, even though they comprised only 11% of the total number of inserted pauses, seems to alter the natural work-pause pattern more substantially. Although current applications focus mostly on implementing micro breaks, these findings indicate that new applications should preferably support macro breaks that last from five to eight minutes. By specifically designing for macro breaks, new possibilities arise because of the extended duration, which – in contrast to micro breaks – allows for an increased variety of small activities.

Most longer breaks, with durations of ten minutes and more, such as type 3 (lunch, coffee, or tea breaks) and possibly also 4 (unplanned breaks), are usually taken away from the computer. Even the shorter macro breaks can be an opportunity to get away from the computer completely, by paying a visit to the water cooler, coffee machine, toilet, or meeting with a colleague. However, this article focuses on the support of macro breaks taken in front of the computer. The reasoning for this exploration is that these breaks can be integrated smoothly into the workflow and might create less unintended cognitive stress as compared to the more disruptive (physical) activities away from the computer. Furthermore, it is assumed that the required effort will be low and with that the threshold to take these pauses. Additionally, the effect of physical activity during short breaks should not be overestimated, as indicated in the paragraph 'Effectiveness of existing break software applications'. Finally, this choice for facilitating macro breaks in front of the computer enables the use of new media in WRULD prevention, which is rather new from a designer's perspective.

The authors are aware that additional pauses of longer duration with both cognitive relaxation and some physical exertion, away from the computer (e.g. lunch walks or exercising in a company's fitness room), might be more effective with respect to WRULD prevention. However, since corporate environments might value (short-term) productivity over health, managements' and workers' incentives for such schemes might be lacking.

Product idea: Watching video clips during macro breaks

A product idea, aiming for cognitive relaxation next to physical relaxation during macro breaks taken in front of a computer, is presented here. This idea was designed during the second author's master thesis project. It should be emphasised that this product idea is an illustration of the aforementioned line of thought rather than an elaborated product design.

The idea aims at mental distraction from the actual work tasks by means of personalised entertainment. Besides the aforementioned considerations, an important reason to develop this product idea was to give the user a rewarding experience during the time a break is taken, rather than an unwanted waiting experience.

The idea is an application that shows short video clips (Figure 5.1a) during macro breaks. Content on e.g. travel, wildlife, or sports can bring a welcome cognitive variation. By customising the content to the user's interest, increased cognitive relaxation is expected to occur. A personal profile and ratings (Figure 5.1b) could allow for customising – and over time improving – the offered content. Many Internet applications like Spotify, YouTube, and Amazon, which are all online applications that offer traditional relaxing activities like listening to music, watching videos, or shopping, are at present not yet leveraged for WRULD intervention. The embedded functionalities in these applications may further support cognitive relaxation during macro breaks taken at the computer. Breaks providing short video content require no physical input by the user – just watching and physically resting. Nevertheless, these will offer possibilities to unload working muscles (e.g. by taking the hands off mouse and keyboard and putting them in the user's lap) and change the user's working position. Sending a clip to a friend or colleague after watching it – comparable to the standard option in YouTube, for example – can provide for some small talk at the water cooler, possibly improving the work floor socially. Because low social support was identified as a risk factor for elbow/wrist/hand symptoms in a study by Van den Heuvel [5], this application might have accompanying benefits with respect to WRULD prevention.

a *b*

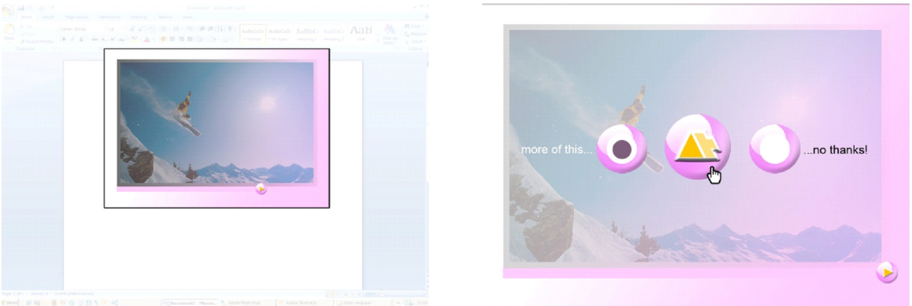


Figure 5.1. Two screenshots of the idea: watching (a) and rating (enlarged) afterwards (b).

User evaluation

The idea was evaluated in a small user test. The goal of this user test was twofold: Investigating the extent of cognitive relaxation during computer work with video-supported macro breaks, and identifying potential short-term advantages and disadvantages of the product idea.

> METHOD

Participants

Ten subjects (6 females, 4 males; age between 22-56, mean age 32.3 years) participated in a user study. These participants were academic staff members (5) and students (5) of the Faculty of Industrial Design Engineering at Delft University of Technology. Six participants had WRULD complaints, located in the neck, shoulder, lower arm, upper arm, wrist, hand and / or fingers (4 once a year, 2 once a month), and four participants were free of WRULD complaints. The duration of the complaints varied from less than 1 hour to a couple of days. The seriousness of the complaints, expressed in frequency x duration, varied from 1 to 576 hours per year (mean 115.5 hours a year). Most complaints were not very severe (less than 50 hours a year).

Stimuli and apparatus

A limited version of the video clip application was simulated by a Web-based prototype in a local server environment. This prototype offered video footage of African wildlife assuming that this was to most people's interest. The customisation feature based on personal profile and ratings was not included. The prototype was installed on a laptop (MacBook Pro) and positioned on the participant's desk next to his or her own computer. The prototype ran for 3 hours. Most of the time the laptop screen showed a book icon (Figure 5.2a), indicating working time laps. After 20 minutes the screen showed the first frame of a nature video and a 'play' button (Figure 5.2b), indicating that a video break could be taken. Feedback on the targeted frequency (set every half hour) of taking video macro breaks was displayed by means of a coloured contour around the first video frame (discretional rest breaks with feedback on rest break behaviour in order to improve the integration of the break system with the working tasks, as recommended by Henning et al. [15]). The initial contour was green, after 4.5 minutes the frame turned orange (Figure 5.3a), and after 9 minutes the frame turned red (Figure 5.3b), and some of these colour transitions were accompanied by modest auditory signals. Subsequently, when not being watched after 10 minutes, the video frame reduced in dimension and moved to the left lower corner of the screen (Figure 5.4a), where it could be activated at a later stage or completely omitted. The prototype programme offered a total of 6 video clips with a duration of 5 to 6 minutes with 30-minute intervals in the 3 hours' running time of the prototype software. A headset (for video sound and auditory signals) was made available for use in shared workspaces.

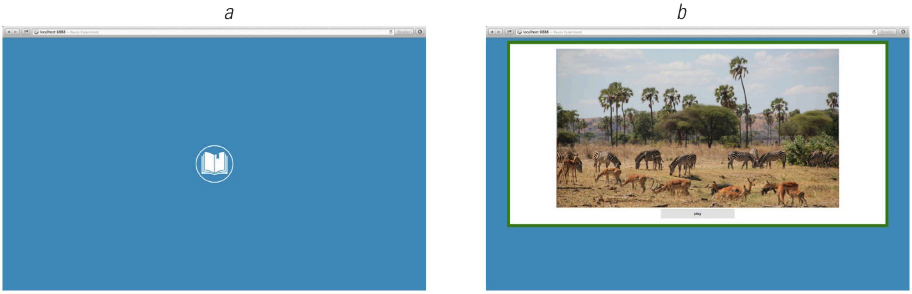


Figure 5.2. The application indicating working time laps (a) and the first reminder of a video break to be taken (b).

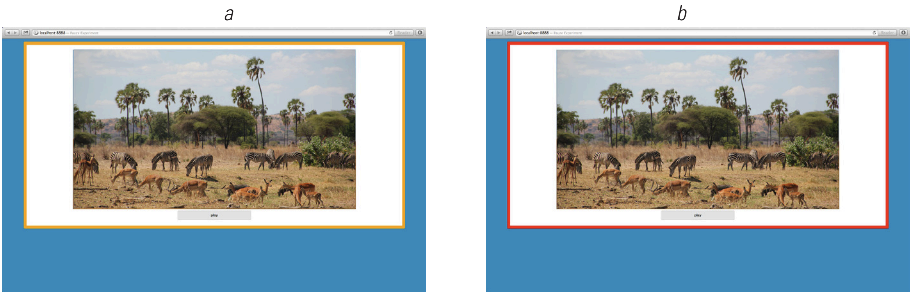


Figure 5.3. After 4.5 minutes the frame turns orange (a), and after 9 minutes the frame turns red (b).

Procedures

Prior to the experiment, participants received an instruction and a short demographic survey by email that included questions about age, gender, possible WRULD complaints, and experienced cognitive load (private- and work-related). In the instruction, participants were asked to plan in advance 'mentally demanding and computer-mediated' work activities they were actually engaged in for the 3 hours' time span of the experiment. In order to create a dedicated work attitude, the participants were stimulated to set a goal for what had to be finished within the given time. The location of the experiment was the participant's personal workspace (for academic staff members, Figure 5.6a), or a reserved office for personal use (for the participating students, Figure 5.6b).

At the start of the experiment, the subjects received a written instruction indicating the aim of the experiment, i.e. to evaluate an alternative way of break-taking during computer work by means of watching short nature videos. Furthermore, it was explained that these would be shown on a laptop next to the participant's personal computer. Participants were asked to cease all computer interactions during the video breaks by removing their hands from the keyboard and the cursor control device (f.i. mouse), to turn their chairs in order to have a perpendicular view on the laptop, to avoid looking at their working screen, to sit back in their chairs, or to move somewhat, and to relax for the duration of the rest break. They were asked to try watching all videos (offered every half hour) if possible, but in case of concentrated working periods, watching could be postponed to a more convenient moment or the film could even be skipped. The meaning of the book icon, the contour's colour coding, and the auditory signals was made clear to the subjects as well. Participants were prepared to come across several VAS scales (10-point scale) on their perceived feeling of stress / relaxation displayed on the laptop screen during the programme. Communicating with others or leaving the workspace was allowed, but only for a limited time (5 to 10 minutes).

Measures

After completion of the 3 hours' working session, participants were interviewed about their perceived cognitive load during watching the videos, during the work spells, and during the 3 hours' experiment as a whole. Furthermore, participants were asked to imagine a working session with similar computer-mediated tasks and in a similar environment as the experimental session they had just finished. The expected differences in their perceived cognitive load and productivity during the 3 hours' experimental session in comparison to 'this working session without video interventions' was questioned. In addition, the revitalising effect during the work spells after the video breaks was examined. The last part of the interview focused on their overall opinion of the video-supported macro break programme including potential short-term advantages and disadvantages of the product idea, and possibilities for product improvement were discussed. Finally, two ideas for video content personalisation were proposed and subjects' opinions towards these ideas were questioned.

Participants' perceived cognitive load was measured by means of a VAS scale (10-point scale) displayed on the laptop screen at the start of the programme, at 2 moments during the work spells (Figure 5.4b), and at 2 moments during the video-watching periods (Figure 5.5b). The VAS scale representations were all accompanied with the same contour colour coding principle and modest auditory signals as used for the videos. Initially the frame was green, it turned orange after 4.5 minutes, and red after 9 minutes, and disappeared after 10 minutes when ignored by the subject. Both the colour coding and the auditory signals were used to remind the subjects to fill in the VAS scale. This system enabled the participants to integrate this small task into their activities because they had the choice to respond immediately, or to postpone (or omit) the completion of the VAS if they had cognitively demanding work to do or were too much involved in watching the videos.

Analysis

As the VAS scores (Figure 5.7) only indicate the subject's perceived cognitive load at given moments, they were solely used as a trigger for the more general interview questions on perceived cognitive load during the entire work- and watching spells. The subject's answers to the interview questions were written down and grouped per question in a spreadsheet. General tendencies were indicated.

a b

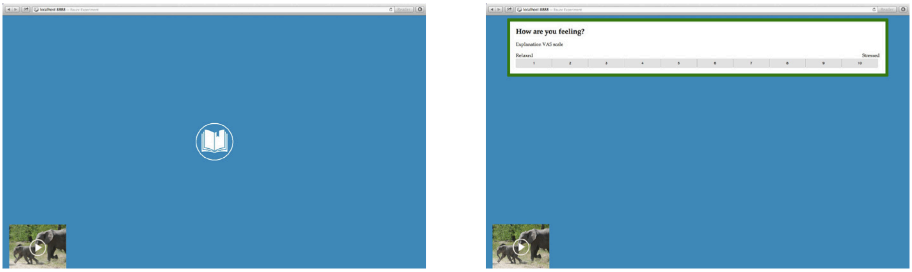
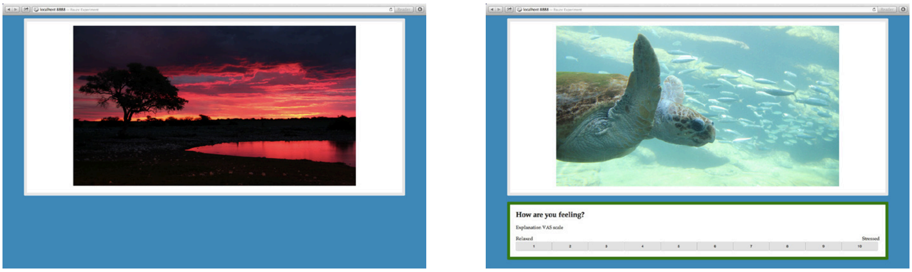


Figure 5.4. Continuing working, video being ignored and reduced (a) and VAS reminder in work spell (b).

a b



Figures 5.5. Watching video (a) and VAS reminder in watching spell (b).

> RESULTS

The participants performed various working tasks during the 3 hours' experimental session. Subjects were writing and reviewing scientific articles and reports, worked on their portfolio and research reports with graphical software, were searching the Web for information, made overviews in spreadsheet software, and used their email programme. In general, subjects were able to work with (great) concentration. Only one participant indicated to have worked with 'moderate' concentration due to distraction by work-related interactions with colleagues and working on multiple tasks.

Most participants watched the videos quickly (few seconds till few minutes) after appearance of the first reminder pop up. Three out of the 60 videos offered to the 10 participants were completely omitted because of work pressure, multi parallel working tasks, and having just watched a previous video. One videos was minimised - not being watched after 10 minutes -, but activated at a later stage. Two participants considered the frequency of video reminder appearance as 'good' and 8 participants preferred a longer time span between the appearance of these reminders, of which 4 participants specified to appreciate a time span of three quarters of an hour above the actual half an hour. Most participants found the duration of the videos - 5 till 6 minutes - just good. Three subjects would rather have shorter videos and one subject longer ones.

Figure 5.6ab. Two participants in their experimental settings.

The majority (7 out of 10) of the participants perceived the cognitive load during video watching as 'low' or 'very low' (one participant reported a 'holiday feeling'). Two participants mentioned a 'varying' cognitive load caused by work periods with multiple and demanding tasks including verbal interactions with colleagues, alternated with dedicated computer work in which watching the videos could easily be integrated. One participant felt distracted and irritated by the videos, because they appeared too often and interrupted the workflow. Four participants spontaneously closed their laptop to also physically set their work aside. The cognitive load during the work spells varied strongly, mainly depending on the work pressure of the tasks at hand. Some participants were under pressure because of deadlines; others had just finished their year of study and were only doing less urgent preparations for the next year. Evaluating the 3 hours' experiment as a whole, most (6 out of 10) participants judged positively ('refreshed feeling after relaxing breaks', 'the videos helped to reduce cognitive load' and 'fixed periods of work and rest made me focus on my work') on their perceived cognitive load, 3 neutral ('First, I had to get used to the programme' and 'First half it went up and second half down'), and 1 negative ('high cognitive load because of irritation by the videos'). Being asked to imagine a working session of similar duration, with similar computer-mediated tasks and in a similar environment, but without video interventions, and to compare their perceived cognitive load of that situation with the 3 hours' experimental session, 6 out of 10 participants expected to experience a 'lower' cognitive load during the experimental session, 2 the 'same' and 2 participants a 'higher' cognitive load. Motivations for an expected 'lower' cognitive load were being able to continue working for a longer time until a large break needed to be taken, a stronger concentration and appreciation of the structured work/rest scheme (being more aware of time). Subjects reported 'same', because on the one hand they felt they lost working time when watching the videos, but on the other hand they valued aspects like being more relaxed or being able to continue working for a longer time before large breaks needed to be taken. The 2 participants who expected a 'higher' cognitive load in the experimental session felt they preferred their own pattern of break-taking and experienced too much distraction from their work by the videos.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Mean
VAS 1 - start	4	4	4	2	2	7	7	3	3	4	4,00
VAS 2 - work	5	3	MIS	4	1	5	8	4	4	5	4,33
VAS 3 - work	3	4	3	6	2	6	MIS	5	4	4	4,11
VAS 4 - movie	4	2	2	8	1	7	6	3	2	1	3,60
VAS 5 - movie	3	3	3	9	1	8	MIS	1	2	1	3,44

Figure 5.7. The VAS scores of the 10 participants, indicating the subjects' perceived cognitive load at given moments. These momentary scores were solely used as a trigger for the more general interview questions on participants' perceived cognitive load during the entire work- and watching spells. MIS = participant did not fill in the VAS scale or skipped the movie in which the VAS scale was shown.

Making a similar comparison for the expected productivity between a working session with and without the video interventions, 5 out of 10 participants indicated a 'higher' productivity during the experimental session, 3 the 'same' and 2 a 'lower' productivity. Motivations for an expected 'higher' productivity were the structured work/rest scheme (with rest breaks of defined duration, different from self-initiated breaks that can easily run out of time), avoiding an overloaded mental state, and longer working hours until a large break became necessary. Subjects who reported 'same' found it hard to weigh the advantages and the disadvantages of the programme in terms of productivity. One of these subjects added to expect a higher productivity in the long run if the programme is used on a daily base. One motivation for an expected 'lower' productivity was the fact that the offered video break pattern did not match the preferred individual break scheme, was time consuming, and was therefore counterproductive.

Eight out of 10 participants indicated that they experienced a revitalising effect during the work spells after the video breaks. These participants reported to have experienced reduced mental load after the breaks, to have a new mindset, to be more relaxed, to feel more pleasant, to have less need for a large break, and to be less tired in the head. Two subjects indicated not to have experienced a revitalising effect. One reasoning was the need to mentally pick up work after the video breaks, which cost time and created irritation.

Four participants evaluated the overall video-supported macro break programme as positive. They appreciated the programme as a whole, the created structure, the fact they could work longer hours, the nature theme of the videos, and indicated the programme as comforting, relaxing and rewarding. Another three subjects felt positive about the cognitive relaxation ability of the programme but questioned some physical aspects. They liked the programme to take their mind off things, considered the programme as something really new, and found the videos very interesting. On the other hand they commented that apart from the cognitive relaxation realised by the videos, physical movement, such as walking away from the screen, was still desirable. They felt somewhat bound to the screen and one subject mentioned also the lack of relaxation for the eyes. Two other participants mentioned both positive and negative aspects in regard to the cognitive aspects of the programme. They appreciated the relaxation by the videos. But one of them considered the programme to be again something ‘extra’ to keep an eye on and the other felt that the break-taking reminders displayed by the programme and the individually preferred moments of break-taking, were sometimes still not synchronised. One subject found the programme annoying and distracting and was concerned about the social aspect; what would other people think of watching movies in working time?

Looking at possible influences of the existence and severity of WRULD complaints on participants’ reported evaluation of the former aspects ‘perceived cognitive load during video watching’, ‘perceived cognitive load during work spells’, perceived load during the 3 hours’ programme’, ‘comparison of their perceived cognitive load during video supported working session with similar working session without video interventions’, ‘comparison of their perceived productivity during video supported working session with similar working session without video interventions’, and ‘the revitalising effect during the work spells after the video breaks’, the results show that both subjects ‘without’ and ‘with’ WRULD complaints belong to the group of participants being ‘positive’ about these aspects of the functioning of the programme. The two subjects who evaluated these aspects mostly negatively, both didn’t have WRULD complaints. A similar picture can be drawn when looking at the ‘overall opinion of the video-supported macro break programme’.

When being asked for possible improvements of the programme, subjects suggested to make clear to the users of the programme that physical activities are still allowed, or even to let the programme stimulate users to move from time to time like walking away from the computer (3 subjects). Another suggestion was to personify the videos’ content according to subjects’ personal interest, possibly also work-related (2 subjects). Other proposed improvements were to make the timing and duration of the videos adjustable in advance (2 subjects) based on personal preferences and expected types of work activities, to create indications for the duration of the videos, and to display the videos on a larger screen.

Seven participants sympathised with the proposed idea to be able to choose their video theme based on personal preferences. The common opinion was that the theme should be relaxing and not trigger thinking of daily duties. Two subjects felt ‘neutral’ towards this idea because on one hand they liked to express their theme preferences but on the other hand they liked to be surprised by the topic (1 subject) or felt that nature was the most relaxing theme amongst all alternatives (1 other subject). One subject couldn’t imagine any interesting topic for this purpose.

Four participants favoured the last proposed idea of supplying personal video content for the programme, such as footage of holidays, hobby's, their family, etc. They expected to be cheered up by these films or found the idea time saving (no time needed for watching these topics at home). One participant felt 'neutral' towards this idea because personal items can also distract too much or trigger thinking. Five participants stated they wouldn't be interested in this idea because they expected the films to trigger thinking of personal duties, creating extra cognitive load, and preferred more 'restful' topics without a connection with their personal lives.

> DISCUSSION

Ten participants contributed to this user test. Because of this small number, the outcomes contain no statistical significance. Nevertheless, the preliminary outcomes give some relevant insights and leads for further development of the programme.

Six participants experienced WRULD complaints, and four participants were free of these complaints. Most complaints were not very severe. There were both subjects 'with' and 'without' WRULD complaints who felt 'positive' towards the main aspects of the programme. The two subjects who evaluated these aspects mostly negatively, both didn't have WRULD complaints. Because of these small numbers the influence of the WRULD factor on the participants' evaluation of the proposed programme could not be established.

Although the basic idea of the video-supported macro break programme is to remind the users in a gentle, unforced way to take a physical and cognitive break, allowing that users postpone or even omit the video-supported break, the experiment outcomes show that the integration of the video watching in the workflow still needs attention. Because of the experiment set-up in which subjects are being asked to participate and to evaluate the programme, the pressure on the subjects to - strictly - follow the offered break pattern might be higher than in a natural context. The experimental set-up might also be of influence on the participants' frequency and duration of leaving the workspace and moving naturally around, although participants were told this was allowed. The outcomes related to the physical aspects and workflow integration must be seen in this light. However, the authors value the ideas related to the personalisation of the programme in terms of timing of the video reminders, duration of the videos and video content preferences.

Another limitation of the experiment set up was the programme running on a separate laptop. For practical reasons it was impossible to run the programme on the individual working computers. Consequently, it might have been easier to disconnect from the working tasks on the working computer and to concentrate on the videos as compared to the situation in which the tasks are waiting at the background on the same computer.

An attempt was made to evoke a dedicated working attitude by asking the participants in advance to plan 'mentally demanding and computer-mediated' work activities and to set a goal for what had to be finished within the three hours' time frame. Still some uncertainty remains related to the perceived stress level in the experiment as compared to a real working setting in which deadlines have to be met and the effect on for instance the willingness to take the breaks and the over all evaluation of the programme.

> CONCLUSION

The outcomes of the experiment with the video-supported macro break programme show that computer work alternated with watching nature videos of 5-6 minutes results in a low perceived cognitive load during watching the videos, in particular when workers can concentrate on the programme without too much interference from others. The perceived cognitive load during the work spells seems to be strongly depending on the work pressure of the working task at hand. The evaluation of the complete 3 hours' programme (including both breaks and work spells) results mainly in positive judgements on perceived cognitive load. People feel more relaxed, refreshed and more focussed on the working tasks. Compared to a similar working session without video-supported macro breaks, it is expected by the majority of the interviewees that with the proposed programme the perceived cognitive load will be lower; longer hours can be worked before large breaks (type 3 or 2) need to be taken and the offered structure by the regularly offered macro breaks will result in improved concentration. Considering a similar comparison, the most frequently reported expectation is that productivity will be higher with the proposed programme, because of the structured work/rest scheme, the predefined duration of the rest breaks, avoidance of an overloaded mental state and the longer working hours until a large break becomes necessary. Furthermore, the outcomes indicate that a large majority of the interviewees experience a revitalising effect (a new mindset, less tired, more relaxed and feeling pleasant) during the work spells after watching the videos.

Apart from these positive considerations, a small minority is critical towards the previous mentioned aspects; these interviewees experience distraction and irritation when watching the videos, find the frequency of the appearing video reminders too high, experience them as interruptions in their workflow, all resulting in a high perceived cognitive load during watching the videos. They expect to perceive a higher cognitive load with the video-supported programme when compared with a similar working session without the programme because they experience distraction from their actual work by watching the videos and prefer their own pattern of break-taking. Furthermore, they consider the programme to be counterproductive because of the mismatch between their preferred individual break scheme and the offered video break pattern.

The evaluation of the overall video-supported macro break programme shows that the cognitive relaxation ability of the programme (comforting, relaxing, rewarding and taking your mind off things) is predominantly greatly valued, but there are some doubts about the physical aspects. Because of the video-supported programme, people feel somewhat ‘bound’ to the screen. Besides the cognitive relaxation offered by the programme they need their physical movement like walking away from the computer or doing more extensive physical exercises. Furthermore, the evaluations underline the need to smoothly integrate the offered macro breaks in people’s personal workflow, taking into account their type of tasks and personal break-taking preferences in terms of duration of the videos, and timing of the video reminders (and thus the duration of the work spells).

Suggestions for improvement as proposed by the interviewees are: making clear that physical movements are allowed when following the programme, stimulation of physical movement by the programme, and personalisation of the videos’ content according to subjects’ personal interest. Nature is considered a relaxing and interesting theme. Alternative themes can also be work-related. Personal footage of hobby’s, holidays, or family might be less suitable because these can trigger thinking of personal duties and can therefore be counter effective in terms of reducing cognitive load. The preferred duration of the work spells is three quarter of an hour instead of the half an hour as used in the experiment.

> GENERAL DISCUSSION

Only limited evidence supports the conviction that existing break software is beneficial to computer workers’ health. This is not opposed to the fact that breaks and physical variation are important. The authors’ aim is to evaluate the characteristics of existing break software that might counteract its effectiveness and to explore pathways for new alternatives. A still very conceptual idea is presented in which an attempt has been made to resolve the conflicting situation of physical and mental aspects of relaxation. By focusing on inducing additional macro breaks, it is assumed that the natural working pattern of computer workers can be altered more substantially. Furthermore, attention was paid to a more positive break perception in the sense of experienced rewarding. An evaluation of this idea, being tested only to a limited extent, is shown in the SWOT analysis of Table 5.1 and followed by recommendations for further development.

Table 5.1. Watching video clips during macro breaks

Strengths	**Weaknesses**
> Rewards break-taking. > No physical input required, just resting or changing physical position. > Focus on cognitive relaxation besides physical relaxation. > Personalised solution for relaxation (type of video footage, frequency, and duration). > Indication for positive short-term cognitive relaxation and productivity (concentration, longer hours before large break) effects. > Potential for positive long-term health and consequently productivity effects. > Intelligent personal profile through rating of the offered videos. > Improved social support. > Semi-voluntary, not imposed nor dominating the work screen.	> Watching the videos takes time. > Integration in the workflow needs attention; adjustable timing and duration of the videos depending on working tasks and personal preferences. > Mobility (and relaxation of the eyes) needs extra attention because of screen/seat bound relaxation; stimulation of small physical activities during watching videos and walking/ exercising at other moments of the working day. > Content of the video breaks have to be well-tuned to the users' preferences. > Users' own responsibility for relaxation and health by taking these voluntary breaks at their own discretion. > Unwillingness to respond to video reminders in case of high work pressure.
Opportunities	**Threats**
> Growing attention of corporate environments for employees' well-being and health in relation to productivity. > Substantial student population. > Attention for students' health.	> Employees lack of acceptance within corporate environments; a too high fun factor might create negative associations on the side of the management. > Ability of employees to mentally pick up work after watching the video breaks. > Limited access to Internet for employees. > Employees restricted by company's email system usage terms for non-work-related messages. > Economic downturn, fear to show awareness of health issues (fear of losing the job).

Whether the idea of video-supported macro breaks would make its way in corporate environments is unknown. Although the authors have confidence in the application's functionality, a too high 'fun factor' could result in adverse associations by management. Moreover, companies' Internet access might be limited, and / or employees' use of the company's email system for the purpose of sending non-work-related messages might be restricted. The application's compatibility with the working environment of students, for example, is probably higher. WRULD is a problem of serious magnitude amongst this target group, which should receive large attention. At the Faculty of Industrial Design Engineering at Delft University of Technology, for example, 60% of the students suffer from WRULD complaints in varying degrees of severity [16]. Furthermore, the results of the experiment emphasise that break-taking behaviour is very personal and the integration of the video-supported breaks in the workflow needs extra attention; timing and duration of the video breaks have to be adjustable to a certain degree, depending on working tasks and personal preferences. As well as the content of the video breaks have to be well-tuned to the users' preferences. Nature seems to be a relaxing and broadly appreciated theme. Work-related topics, not too 'heavy', might be appropriate as well as indicated by the experiment. Moreover, because of the screen- and seat bound nature of this idea, the user's mobility - and relaxation of the eyes - needs extra attention. Small physical activities during watching the videos need to be stimulated as well as it has to be emphasised more in general that larger movements as walking and exercising remains indispensable for healthy computer working.

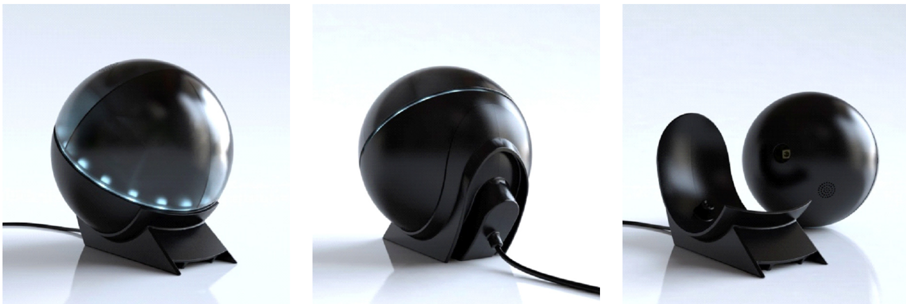
Another product idea designed during the second author's master thesis project, and building on both aforementioned design opportunities is a dedicated physical input device for Internet tasks. This product idea is intended to reduce mental stress resulting from inactivity during physical break time and to maintain productivity. This idea strives to unite the improvement of work-to-rest ratios with Blatter and colleagues' [7] second most promising measure for WRULD prevention, namely examining the preventive effectiveness of new pointing and input device usage. While traditional computer mice and keyboards are widespread and very useful, they can be a significant source of discomfort due to forearm pronation, planting the base of the wrist on the desktop resulting in contact pressure near the carpal tunnel, wrist extension, ulnar deviation, and extended finger postures [24].

The targeted user groups are computer workers in research, creative, or managerial functions – in contrast with, for example, administrative jobs with more routine activities. This second product idea is an alternative input and pointing device, specifically designed for Internet tasks. These are assumed to be cognitively low demanding and possibly even entertaining. Examples are looking up words in the dictionary, finding pictures to support a presentation, or executing search queries using Google or Wikipedia. Performing such tasks with an alternative input device may lead to cognitive and physical relaxation. Since these moments occur spontaneously, they reduce the need for the more dedicated rest breaks that can be stressful close to deadlines.

A spherical tool (Figures 5.8a and 5.8b) with a wireless connection to its docking station (Figure 5.8c), allows the user to choose work positions and movements, thus adding to mobility and reduction of static muscle tension in front of the computer. The device is preferably controlled from the user's lap (Figures 5.9a and 5.9b). It realises text input and confirmative mouse actions – left, right, and double clicking – via speech recognition. Speech recognition used to be characterised by long learning curves, but in recent years has become better capable of, for example, listening to specific voice patterns and understanding commands consisting of multiple words.

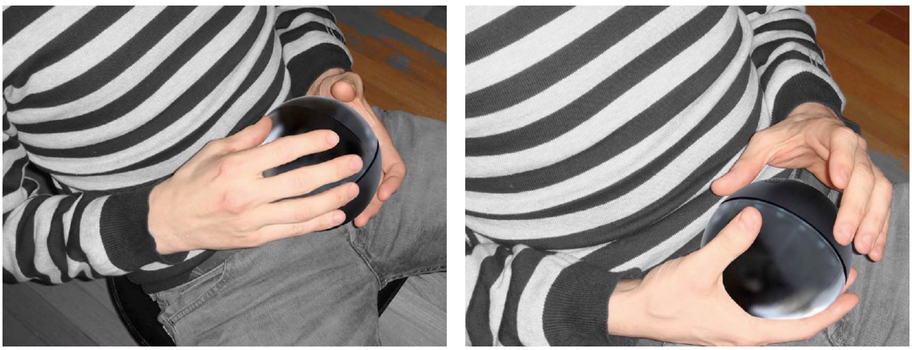
Internet voice-controlled text input is assumed to be not too disturbing in open-plan offices, since these are often short commands. E-mail functionality, requiring longer text input, is therefore excluded. The navigating mouse actions – that are not optimally controlled using speech recognition – are realised with gyroscopic technology, as introduced in the gaming industry by Nintendo's Wii remote. The gyroscope translates rotation into X-Y cursor movements on the screen. Because the movements of the cursor on the screen correspond to the rotational direction of the gyroscope, it is expected that navigation is easy to learn. More important than the actual specifications of the device is the fact that this idea allows a rethinking of work tasks and a consideration of whether variation in input for specific tasks could help to define breaks – in the sense of cognitively and physically less demanding or even relaxing episodes – in computer work.

a *b* *c*



Figures 5.8a-c. The input device and its docking station

a *b*



Figures 5.9ab. The input device in use.

Regarding this second product idea, information has to be obtained related to the Internet behaviour of the targeted computer workers, and differences per job or work task have to be charted. In addition, the physical handling of the spherical tool has to be evaluated with respect to the assumed reduced static muscle tension. Because this product idea is based more on the principle of 'task rotation or job enlargement', as expressed in OSHA's eToo [10] (or 'changes in activity' in the Council Directive 90/270/EEC) [9], rather than on complete disconnection from work, it might be more broadly accepted (corporate employers, employees, students, etc.). On the other hand, acceptation might be limited in shared working environments because of the risk to disturb colleagues by the speech recognition feature. Apart from these recommendations regarding this second idea, which is not being tested, a SWOT analysis is shown in Table 5.2.

Table 5.2. A dedicated physical input device for Internet tasks

Strengths	**Weaknesses**
> Potential for cognitive relaxation besides physical relaxation (variety in physical activity). > Integrated in the workflow, no time consuming. > Potential for positive short-term cognitive relaxation and productivity effects. > Potential for positive long-term health and (consequently) productivity effects. > Potential for broad acceptance (corporate employers, employees, students, etc.) because of 'task rotation' and 'change in activity'.	> Associated with specific work tasks. Frequency and duration of breaks dependent on type of job and work tasks. > Disturbing colleagues in the work environment (noisy). > Physical handling of the tool might contribute to physical loading (muscle tension). > Puts some strain on the voice. > Latency (1 sec) of speech recognition.
Opportunities	**Threats**
> Health issues (WRULD) related to mouse use. Replacement (partly) of this 50-year-old input device [24]. > The overall trend of using natural user interfaces (NUIs) and easy to learn applications [25, 26].	> Too much work pressure, unwillingness to change input devices. > Economic downturn, fear to show awareness of health issues (fear of losing the job).

> GENERAL CONCLUSIONS

Overall, it seems to be challenging to create a widely supported design for the purpose of combined physical and cognitive relaxation in computer work. Certainly, the effects of both ideas should be thoroughly tested with potential users in order to make well-founded statements about their functioning. Even more importantly, the potential health effects and productivity implications of both ideas have to be investigated for the short and the long term [8]. The recommendations in the aforementioned study on work-pause patterns [23] to support the administration of macro breaks are based on the intention to alter users' working behaviours in a positive way, but do not yet give a guarantee for healthy computing nor high productivity. Nevertheless, the very preliminary results of the small-scale user test with the video-supported macro breaks idea indicate that most users perceive this application as cognitively relaxing and productivity improving.

Future research with more elaborated concepts of the two ideas based on the former recommendations should indicate whether these solutions can be characterised as 'comfort improving', 'WRULD complaints preventing', or even 'reducing existing WRULD complaints'. A positive long-term health effect will have a positive influence on the long-term productivity effect, which is a key factor for managements in the decision making process for buying such future products. Although at this stage the two ideas are still very preliminary, they do illustrate new potential for the realisation of health and productivity aspects in computer working by specifically taking into account the cognitive aspects of breaks.

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> NOTES ON CONTRIBUTORS

The second author, Sander Van Lochem, defined the two design opportunities and designed the product ideas presented in this article during his master thesis project [27] at the Faculty of Industrial Design Engineering at Delft University of Technology. The first author, Marijke Dekker, is a university staff member and belonged to the supervisory team of the second author's master thesis project. She is the coordinator of the Working Group on RSI Prevention (WRULD Prevention) at the Faculty of Industrial Design Engineering at Delft University of Technology [16, 17], studies the topic WRULD, undertook an additional literature review for this article, and performed the user tests with the Web-based prototype. The third author, Johan Molenbroek, is also a university staff member at the Faculty of Industrial Design Engineering at Delft University of Technology and supported the writing of this article.

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Submitted for publication

Dekker MC, Ludwiczak MP, Vink P. **A smart drinking bottle contributing to the health of computer workers.**

CHAPTER 6

A SMART DRINKING BOTTLE CONTRIBUTING TO THE HEALTH OF COMPUTER WORKERS

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> ABSTRACT

Background Work Related Upper Limb Disorders (WRULD) is the most common syndrome affecting contemporary computer workers, next to Computer Vision Syndrome (CVS).

Objective To develop a health preserving device to prevent WRULD and CVS among computer workers through encouraging them to take breaks at work.

Methods The concept was developed in a master thesis project using the Double Diamond Approach, applying both diverging and converging thinking. The desirability of the concept was investigated by a small group of potential users by means of an online questionnaire.

Results A smart drinking bottle reminds its users to drink water and to refill the object when it is empty. The users keep their hydration levels high and take breaks from their screen work because the principle is based on drinking and going to the toilet, two strong physiological needs. The working of the bottle is based on sensing the amount of water in the bottle and measuring user's working time and break time according to the recorded actions with the mouse. The product service system is communicating with the user through different light patterns on the bottle. The results of the questionnaire show that the concept has potential for a majority of the respondents.

Conclusions The developed break reminding product-service system based on human physiological needs, a new principle to tempt computer users to take a rest from their screen work, seems to be promising. However, the concept needs to be developed further and long term health effects need to be explored.

Keywords WRULD, RSI, CVS, prevention, breaks

> INTRODUCTION

The most common syndrome which affects contemporary computer workers is Work Related Upper Limb Disorders (WRULD), also known as Repetitive Strain Injury (RSI), or Complaints of the Arm, Neck and Shoulder (CANS). The most typical symptoms of WRULD are pain, stiffness, tingling, numbness affecting muscles, tendons and/or nerves in the (upper) back, neck, shoulders, arms, wrists and hands. Surveys of working populations have reported prevalence of 26 to 54 % [1, 2]. Various studies focussed on prevalence of complaints in particular upper body locations show even higher percentages. Highest prevalences are found in the neck (45 to 78 %) [3, 4, 5], upper back (73%) [4], and shoulders (41 %) [5]. Earlier data from the European Foundation for the Improvement of Living and Working Conditions in 2000, based on fifteen European countries, showed that the work of 20% of the office workers causes neck/shoulder pain [6, 7]. Prevalence of hand, wrist and arm complaints are in general lower than those of upper back, shoulder and neck. The upper extremities show prevalence rates between 9 to 47% [3, 5, 7].

Intense screen work can also cause eye and vision-related problems commonly known as Computer Vision Syndrome (CVS). Different terms have been used to describe the symptoms such as eye strain, visual strain, visual fatigue or asthenopia [8, 9, 10, 11]. According to Yan et al. [10], the main symptoms can be divided into eye-related symptoms (e.g. dry eyes, watery eyes, irritated eyes), vision-related symptoms (e.g. eyestrain, eye fatigue, headache) and posture-related symptoms (e.g. pain and soreness in shoulders, neck and back). These posture related symptoms might for instance result from glare, which forces computer workers to remain in an awkward body position, often subconsciously, in an attempt to reduce visual fatigue. Aarås et al. [12] found a clear indication of a relationship between visual discomfort and pain in the neck and shoulder. Richter et al. [13] found that sustained eye-lens load during a near point accommodation task in ergonomically unfavourable viewing conditions with a blurred target, lead to higher trapezius static muscle activity levels, representing a risk factor for neck-shoulder WRULD. Because of such relationships, CVS is in some studies considered a form of WRULD or is included in studies on WRULD prevalence [8, 10, 14, 15]. Many studies have found a reduced eyeblink rate when performing computer work compared with other visual tasks [16, 17, 18]. Lower eye blink frequency is likely to contribute to dry eye symptoms and visual discomfort experienced by computer workers [19] because of a reduced distribution of ocular protecting tear film [18].

The estimated prevalence rates of CVS amongst US workers differ from 14-23% [10] up to 90% [8]. Eye complaints were also investigated in the study among university students of Dekker et al. [20]. Thirty-one (31%) percent of students with average age of 20.0 years with complaints during and after computer work reported eye complaints, compared to the highest scores of 58% in the neck and 53% in the shoulders. CVS carries implications for the wellbeing of computer workers. Although it has not proven to cause permanent damage to the eyes, it can lead to reduced productivity, job satisfaction and decreased performance [21].

Improving work rest patterns is considered as the most promising preventive measure for WRULD problems related to computer work [22]. Multiple studies advise work-rest patterns [23, 24] and not staying in a given position for too long [25]. For instance, 10 minutes of rest for each hour of work had a positive effect on the incidence of disorders in hands and/or wrists of a combined telephone / computer task. [26]. Galinsky et al. [27] found that an addition of 5 minutes breaks each working hour which otherwise did not contain a break resulted in a decrease of work-related discomfort in several body locations (back, neck, shoulder/upper arm region) of data-entry workers. Accumulation of discomfort during work sessions was attenuated by providing the supplementary rest breaks. McLean et al. [28] investigated the effect of break-software-induced micro breaks (30 seconds at 20 minutes intervals, 40 minutes intervals, and at participants' own discretion) during keying and data entry tasks and found beneficial effects of micro breaks on discomfort ratings in the neck, the low back, the shoulder, and the forearm/wrist areas, particularly when breaks were taken at 20 minutes intervals.

Accordingly, various sources suggest that introducing breaks in computer work is also beneficial for the eyes [8, 10, 11, 29]. Clinical optometrists suggest that computer users should after 20 min of computer use, look at something 20 ft away for at least 20 s known as the 20/20/20 rule [9]. After all, eye muscles also require recovery time, just like muscles affected with WRULD. In the case of the eyes, resting means restoring and relaxing the accommodative system [10].

In the study of Dekker et al. [14], possibilities to create a widely supported design for the purpose of physical and cognitive relaxation in computer work were explored by design cases. These were inspired by the notion that it is challenging to make users aware that a break is needed, to actually let them take the break, and to let them successfully 'shut down' from work stress in particular when users are working on cognitive demanding tasks or just want to finish something. The study provides an overview of the type of rest breaks in computer work including the shorter macro breaks with a duration of the order of minutes and micro breaks with a duration of the order of seconds. According to Slijper et al. [30], the administration of macro pauses, alter the natural work-pause pattern of computer worker more substantially compared to insertion of micro breaks. Although additional pauses of longer duration with both cognitive relaxation and some physical exertion, away from the computer (e.g. lunch walks or exercising in a company's fitness room), might be more effective with respect to WRULD prevention, the focus of the Dekker et al. [14] study was on macro breaks because of the assumption that these longer breaks would not always be accepted or practically applicable in corporate environments. However, when evaluating one of the developed ideas with a screen and seat bound nature in a small user test, the user's mobility and relaxation of the eyes, where found to be points for improvement.

Taking the previous experiences into consideration also in the design project subject to this article, the second authors' master thesis of the study Industrial Design Engineering (IDE) at the Delft University of Technology [31], the starting point was to assist computer users with taking physical and cognitive macro breaks and to support short-term mobility. The aim of this project was to create a physical product to encourage computer users to work healthier by taking more breaks. The client of this graduation project was R-Go Tools B.V. [32], a Dutch company specialised in developing ergonomic products. R-Go Tools developed the HE mouse combined with an anti-RSI software, R-Go Break, which encourages users to take more breaks during work. This software counts down the time towards the next break, which should be taken by the user. The working time is measured by recording the movements and the scrolling and clicking of the mouse. When the user stops using the mouse for at least 30 seconds, the timer resets. The measurements of the work-rest ratio's result in different light signals on the HE mouse in order to give feedback on user's behaviour. At the time of the graduation project in 2018, the standard break times of the R-Go Break software were set at 30 seconds break after every 10 minutes of work and 5 minutes break after every hour. The users were able to adjust the time of these micro and macro break durations and of the in-between break periods according to their individual preferences.

> METHOD

In this graduation project the Double Diamond Approach [33] has been applied, in which both diverging and converging thinking were applied when approaching the problem. The process is illustrated in Figure 6.1.

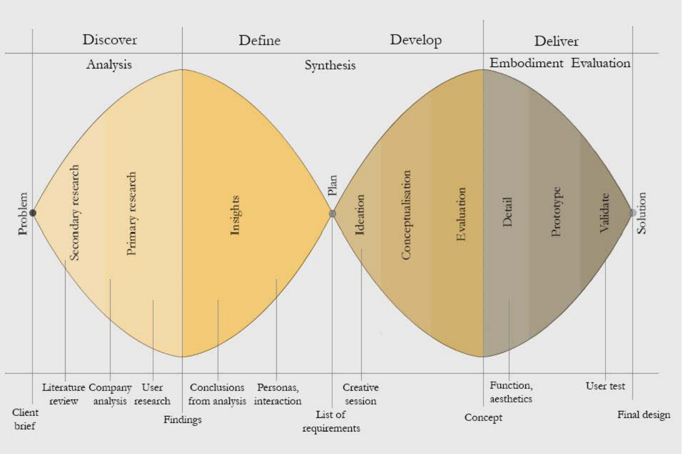

Figure 6.1. The Double Diamond approach used in the project [33].

Accordingly, the project started with understanding the problem by gathering information related to the subject and context (Figure 6.2). Thereafter, attempts have been made to find opportunities in the gathered information and define a clear design direction for further steps. The second divergence involved the development of different ideas and concepts and consequently, choosing the best for the assigned problem. Lastly, the concept was detailed into a feasible solution, at the same time evaluating the concept through prototyping and testing and presenting the final design to the master project's supervisory team and the company.

Figure 6.2. The office environment with the usual objects [31].

The methods applied in each phase, were extracted from either Delft Design Guide [34], Design Kit [35] or inspired by Master theses found on repository of TU Delft [36].

After completion of the master thesis project, the desirability of the concept was investigated by giving a visual impression of the bottle and explaining its functionality online to 13 potential end-users. All participants were asked in an online questionnaire to mention positive and negative aspects of the design and their willingness to use the proposed concept.

> RESULTS

Various design directions were explored. The decisive selection criteria for the chosen design idea were, the break taking reminder must be convincing and accepted by the user, difficult to overlook and easily understood on top of work-related issues, have natural boundaries and therewith gradually preparing the users for the start and the end of the break, make it easy to return to work afterwards, minimise feelings of disturbance and stress, and not be a nuisance to co-workers.

The chosen idea emerged from the assumption that users will be less disturbed by a proposed break if its purpose is something that they already accept. It is widely recognised that humans accept the bottom level of Maslow's hierarchy of needs [37]. The bottom level includes, among others, quenching thirst and going to the toilet. Additionally, there are indications that drinking water can play a role in the prevention of WRULD and CVS since dehydration inhibits the recovery process of over-used muscles [38]. Consequently, it seemed natural that redesigning a cup or a bottle, both so widely used in every office, would be the best option for this type of intervention. This resulted in the development of the Break Bottle, a smart bottle to stimulating computer workers to take breaks based on their physiological needs.

The Break Bottle is a smart bottle encouraging users to refill the bottle, to drink water and, eventually, to go to the toilet. This requires the user to take three related breaks; the first and the last are longer (macro) breaks away from the computer and the second one could be shorter (micro) and taken at the workplace. All three breaks are non-screen bound. Each action results in resting of user's muscles (WRULD prevention) and looking away from the screen (CVS prevention). Although these breaks are based on physiological principles, changes in the appearance of the object give the signals to support the taking of these breaks.

The volume of the tube is approximately 288 ml, which is enough to hold the amount of water that women should drink in two hours (2200 ml / 16 active daily hours multiplied with 2 = 275 ml), based on the advised daily total water intake of 2.2 litre per day [39]. Consequently, the bottle would have to be refilled at least every two hours. Men are supposed to drink more water than women and that is why water intake for women was taken into account as it establishes the minimum number of refilling times.

A light gray colour has been chosen for the bottle since it works well with the green lights placed inside the object. The gray paint and the green lights together make the bottle look either lively or lifeless depending on whether the lights are switched on or off. Figure 6.3 shows the product in the office environment.

Figure 6.3. The bottle placed in the context. [31]

The working principle of the bottle is based on sensing the amount of water in the bottle and the previously mentioned anti-RSI software R-Go Break, developed by the client R-Go Tools, measuring user's working time and break time by the recorded movements and the scrolling and clicking of the mouse. In addition to the Break Bottle, an algorithm was therefore developed in the master thesis project, combining information on number of refills of the bottle, water intake and break occurrence according to the recorded mouse actions. Based on this algorithm a light pattern is displayed on the bottle and communicates on the extent to which the user refilled the bottle enough times, drank enough water and has taken sufficient breaks within a certain time frame. Similar to the anti-RSI software R-Go Break, this newly developed algorithm allows the user to make individual adjustments of the required micro and macro break durations and of the in-between break periods.

If the user behaves 'well', the lighting of the bottle will have an attractive saturated colour as an award. However, if the user fails to refill the bottle enough, drink enough water or to take enough breaks, different levels of temptation to change user's behaviour are introduced by displaying different number, blink rates and green tones of the LEDs. In case of a mild seduction fewer LEDs are involved that are blinking slower. However, if the number of refills, the water intake and the break taking are insufficient, a strong seduction takes place involving more LEDs that are blinking faster. Consequently, different lighting colour tones and patterns should elicit different user responses (Figure 6.4).

Due to the limited time of the master thesis project, the effects of the light colour tones, and patterns could not be investigated. However, several prototypes were made to verify the product's architecture (Figure 6.5) and to perform a small assembly and disassembly test (Figure 6.6).

Figure 6.4. Final concept with light pattern. [31]

Figure 6.5. Prototype to evaluate whether the main functions can be effectively executed in the object. [31]

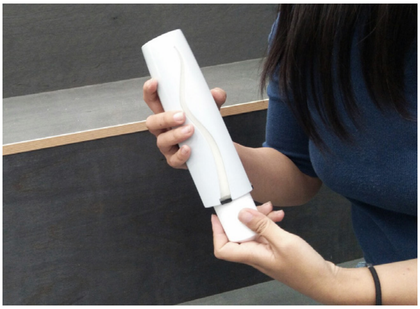

Figure 6.6. Assembly testing with prototype by one subject. [31]

The online questionnaire on the desirability of the concept was completed by 13 potential end-users (53,8% male and 46,2% female) with an age ranging from 21 and 63 years. Almost all participants (92,3%) experienced physical complaints in the last 12 months during or after working with their computer, mainly in their neck/shoulder (83,3%) and their eyes (41,7%). All participants worked more than 4 hours a day with the computer of which 61,5% 6-8 hours and 23,1% more than 8 hours. Macro breaks were taken mostly (76,9%) every hour and by 23,1% of the participants every two hours.

The results showed that 10 out of 13 participants recognised the bottle's potential ability to provoke an action that could separate them from their computer (screen). This action was described as simply taking a break or more precisely indicating the breaks' content such as drinking water, getting moving, relaxing muscles or climbing stairs. Returning key words in the participants' positive answers were, 'stimulating', 'reminding', 'helping', and 'changing behaviour'. There was both appreciation for the physicality of the product (less easy to be ignored compared to current on screen alternatives), as there were some doubts on this aspect (no break reminders in case the bottle would be lost or forgotten, hard to find an eye catching space for it on a full desk).

Five participants doubted or felt negative about the functionality and appearance of the bottle's (blinking) coloured lights. These could be distractive, disturbing the work flow or even create migraine. The distance at which the bottle is placed on the desk relative to the user also plays a role here. The suggested 0.5 meter is too close for one of these participants. Additionally, two participants supposed the lights' functionality as being a reminder might reduce over time as they will get used to the product. One participant considered the product 'demanding' i.e. the product might tell him or her what to do. Also, three participants were concerned about the environmental impact of the product, which may be higher than their current (recycled glass) bottles.

Overall, more than half of the participants (7 out of 13) could see themselves using the bottle as they appreciated its break prompting value. The other participants couldn't for various reasons such as the distraction caused by the product, the lack of environmental friendliness, the potential high price compared to regular water bottles, or the incompatibility with current habits such as drinking tea instead of water.

> DISCUSSION

The aim of this project was to create a physical product to encourage computer users to work healthier by taking more breaks. The proposed smart drinking bottle appears to be a product that naturally tempts users to take breaks from their screen work as the principle is based on drinking and going to the toilet, two strong physiological needs. In order to anchor this rhythm of break taking based on human needs and not allow the user to delay successive steps, the bottle is equipped with feedforward based on varying light patterns. In opposite of the existing on screen break software, this rest break causing concept concerns a physical product. It stands on the desk and can be held and used without having to look at the screen. In the created macro breaks the user is stimulated to become mobile and to walk away from the screen. Furthermore, drinking water is in itself beneficial for computer workers' health.

The results of the online questionnaire show that the concept has potential for a majority (10 out of 13) of the respondents. Participants appreciate the ability of the Break Bottle to remind and stimulate them to interrupt their screen work for a rest break and to drink water as they see the health benefits of both. They also recognise that both aspects can easily be forgotten in their daily routines. Respondents spontaneously reported their preferred opportunities for body movement and muscle relaxation during these break times.

However, the potential users also see drawbacks to the new concept. In particular, there is doubt about the reminding functionality by means of the coloured (blinking) lighting. It might be too distracting, especially because the bottle is placed close to them on their desk. Furthermore, the Break Bottle has to compete with existing low budget, more environmental friendly solutions, like recycled glass bottles or drinking cups suitable for different types of drinks. All in all, slightly more than half of the respondents in our study indicate that they would like to use the product.

The presented concept only sketches the rough contours of the proposed future product and is not detailed yet in relation to functionality, formgiving, technical feasibility nor environmental impact. We can conclude however, that the break taking device based on physiological principles might meet the needs of computer workers. In further development, the first aspect that requires attention is the signalling system - the light colour tones and patterns - which must demand the user's attention at appropriate times in a not too obtrusive manner. In this perspective, the physiological incentives with regard to drinking and going to the toilet will help, because they already have a gradual transition by nature. And these will reduce the need of stimulation by the lighting warning system. Also the application of drinks other than water can be explored.

The working principle of the Break Bottle is based on sensing the amount of water in the bottle and measuring user's working time and break time by the recorded mouse manipulations as also realised in the existing R-Go Break software. Therefore the concept is a product-service system, rather than a physical product alone. The created algorithm for controlling the bottle in these respects needs further development. More extensive future user evaluations with working prototypes are necessary to realise desirable user interactions.

The aim of the Break Bottle presented in this article is to contribute to the computer users health in perspective of WRULD and CVS. Whether we will succeed in this must be investigated in future long-term studies with a more elaborated proposal of the Break Bottle product-service system. Another long- term aspect has to do with habituation and it is therefore necessary to examine whether the behavioural change persists over time or whether users become accustomed to the signals and will ignore them in the long run.

Multiple work-rest patterns in computer work are advised in order to reduce WRULD disorders or discomfort [26, 27, 28]. It must be realised that the type of computer work can differ greatly. The aforementioned advices mostly concern data entry work or combined telephone/computer entry tasks which are very different by nature from more complex and mentally demanding computer tasks of knowledge workers. Furthermore, there will be large individual differences between users related to their needs for healthy computer working. The authors therefore endorse the principle, also applied by the project client R-Go Tools, that the user can set the frequency and duration of the breaks according to his or her physical and mental condition and preferences.

> LIMITATIONS OF THE STUDY

The study concerns the development of a new product-service system. In general it is hard to predict its success. The concept aims to change behaviour, which in itself is a challenge and the user test has been done with only 13 subjects. On the other hand this study shows that it is possible to develop an intervention, which has potential to be accepted by more than half of the intended user group.

The concept of the Break Bottle is based on physical interruption of the work by stimulating the mobility of the user and becoming temporarily detached from the screen work. As discussed previously [14], also the cognitive aspects of rest breaks are important. The fact that the computer worker’s view is turned away from the work on the screen, that the user moves to a different environment and thus acquires different impressions is likely to broaden the mind. Nevertheless, It might be supportive to offer additional training on cognitive relaxation, as described for example by Peper [40].

> CONCLUSION

A water bottle is developed tempting users to drink water and to increase the number of breaks to reduce Work Related Upper Limp Disorders (WRULD) and Computer Vision Syndrome (CVS) among computer workers. The working principle of the bottle is based on sensing the amount of water in the bottle and measuring user’s working time and break time according to the recorded actions with the mouse. A light pattern displayed on the bottle communicates the extent to which the user refills the bottle enough, drinks enough water and takes sufficient breaks within a certain time frame according to set values. Not only refilling and drinking provide rest breaks, but also the resulting toilet visiting. The concept has been evaluated by potential users showing that it has potential for three quarters of the respondents and slightly more than half would like to use the product in future. The idea of a break reminding product-service system based on human physiological needs, a new principle to tempt computer users to take a rest from their screen work, seems to be promising. However, the concept needs to be developed further and long term health effects related to WRULD and CVS need to be explored.

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CHAPTER 7

KEY FINDINGS PER CHAPTER

This chapter is a comprehensive overview of the results from the Chapter 1 through Chapter 6. In Chapter 8, I will further elaborate and contextualise these key findings. In addition, they will be discussed in relation to the research questions as formulated in Chapter 1.

Key findings of Chapter 1

The Introduction describes the rise of RSI complaints among students at the Faculty of IDE of the TU Delft at the start of this millennium and introduces the RSI prevention group, which was established in response to this. Furthermore, three etiological models from the literature, 'Impeded blood circulation', 'The neuro noise theory' and 'Pain reception' are presented of which the author of this thesis believes they represent plausible explanations for the development of RSI. In addition, the main risk factors for developing RSI complaints resulting from a literature study are presented and discussed.

In summary these risk factors are:

Physical factors

> Working in awkward positions [1]
> Working continuously in the same position (static strain) [1]
> Repeated movements [1]
> Precision demands [2, 3 4.
> Prolonged working [5]

Psychosocial factors

> Insufficient opportunities for recovery [1, 5]
> Psychological strain (extreme pressure of work, high levels of stress, high working tempo, mentally demanding work) [1, 2, 3, 5, 6]
> Inadequate social support [1]

Personal factors

> Perfectionism, being strongly committed to the work [5, 6, 7]
> Lack of physical activity, exercise, and/or fitness [5, 8, 9]

Besides providing time to recover, Blatter et al. [5] emphasised the need to diversify tasks. Furthermore, the Health Council [1] underlined the importance of consistent advice, information and reassurance in early stages of the development of RSI complaints.

In the section 'Pain reception' of Chapter 1, the personal risk factors for development towards chronic complaints are described, such as pain catastrophizing behaviour and fear for movement (kinesiophobia). Additionally, lack of physical fitness appears not only to be an important risk factor for the onset and development of complaints, but physical fitness also influences the course of complaints and the prevention of complaints becoming chronic [6].

It was concluded that the study environment and the educational programme of IDE contain many aspects that relate to risk factors for the onset and exacerbation of RSI as reported in literature and listed above. These risk factors formed the theoretical framework for further developing the RSI prevention programme. The two psychological risk factors catastrophizing behaviour and fear for movement were more difficult to address in the group approach of the RSI prevention programme. However, if the presence of these risk factors was suspected for students with more severe complaints, a referral was made to the psychologist of the Students' Health Service (in Dutch 'Studentengezondheidszorg' abbreviated SGZ), general practice, or multidisciplinairy team of the SGZ.

Key findings of Chapter 2

Chapter 2 of this thesis shows that a high number of TU Delft students were consulting the doctors of the SGZ in the period 1999-2003 for their RSI complaints. It was also indicated, that after a medical check-up the SGZ issues a medical certificate for students with more severe complaints, reflecting student's reduced study capacity and study delay, supportive to discuss the possibilities for extra study time and possibly financial compensation from the university or from the Dutch study grants. For both indicators, the number of RSI-related consultations and the accumulated time of study delay as indicated on these medical statements, the Faculty of IDE was the frontrunner among all TU Delft faculties. The Faculty of Architecture scored the second highest in both indicators. For this time period, the financial losses of these individual TU Delft students were estimated at 20,000€, due to their extra study costs and delayed career. And the total financial losses of the university and the government in this time frame were estimated at 350,000€ due to their compensation with extra study grants for these TU Delft students and missed bonuses because of some students dropping out of their studies.

Furthermore, this chapter presents the longitudinal survey on RSI complaints amongst IDE students. Results showed that in the academic years 2000/2001 (n=290) and 2002/2003 (n=155) about 60% of the students experienced complaints, which is substantial. These complaints occurred more often in higher years of studying. Most students experienced complaints once a month or once a week lasting mostly less than 6 hours. Severity results based on the occurrence times duration showed that most complaints were not very severe as these were experienced for less than 100 hours per year. However, somewhat less than a quarter of the complaints were more serious and lasted for 100-800 hours per year. A small category complaints was very serious as these were experienced for more than 800 hours per year (respectively 4% and 9% of the complaints group in the academic years 2000/2001 and 2002/2003). The most often affected body regions were the wrists, shoulders and the neck.

Additionally, Chapter 2 describes the activities of the IDE RSI prevention programme for students - and to a lesser extent IDE employees - aimed at reducing RSI risk factors and therewith complaints.

Key findings of Chapter 3

The unique and large follow-up survey described in Chapter 3, based on the data of 2254 IDE students collected in a period of 10 years, shows differences in time (academic year), in how long students have been studying (year of studying), in daily computer time, all in relation to WRULD prevalence rates and seriousness of the reported complaints. In the investigated time-period 2004-2014 a decrease in the prevalence, occurrence, duration and the two alternative measures for the seriousness of WRULD have been observed from the first (2004/2005) to the third (2008/2009) or fourth (2010/2011) recorded academic year. This was followed by an increase of these values to the fourth or fifth academic year (2013/2014). In this last academic year 2013/2014, the prevalence was only slightly lower than the highest level in 2004/2005. The seriousness LDA (limitation of daily activities) and seriousness OxD (occurrence x duration of complaints) and also its separate factors occurrence and duration, show the highest scores in the last academic year 2013/2014. The values for prevalence, seriousness OxD (and its separate factors occurrence and duration) and seriousness LDA are lower in students who just started studying as compared to students who have been studying for a longer time. However, these patterns over the higher years of studying are not always totally gradual. The given explanations are related to students' freedom in organising their study activities in certain time frames of their studies, and the fact that later in their studies they have learned how to cope with the WRULD risk factors within the IDE environment. The body locations of the complaints that were most often indicated by the complaints group were, the neck (58%), shoulders (53%) and back (43%), followed by the wrists (41%).

Over the five academic years, the less severe complaints of 1-50 hours per year are seen most, i.e. by 58% of the respondents who report complaints. In the last investigated academic year 2013/2014, the highest percentage of students experiencing very serious complaints of > 800 hours per year was found (15%) and also the highest percentage of students experiencing the most serious complaints of > 1600 hours per year (9%). In order to get an impression of the absolute numbers of students concerned, these two percentages are applied on the total IDE student population of the academic year 2013/2014. In that academic year, 2004 students[1] studied at the Faculty of IDE, resulting in 1162 students reporting complaints (58%) of which 174 students with very serious complaints of > 800 hours per year (15%) and 105 students with the most serious

1 Data received via personal contact from Corporate office Strategic Development Data-Insights team TU Delft, https://www.tudelft.nl/en/about-tu-delft/organisation/university-corporate-office

complaints of > 1600 hours per year (9%). Both measures for the seriousness of the complaints (expressed in complaint hours per year and in limitation of daily activities) show highest scores in students who are studying in their 5th/6th/7th year.

The association of self-reported average number of computer working hours per day and the prevalence of WRULD symptoms as found in other studies [10, 11, 12, 13], was confirmed in our findings. The higher the number of computer hours per day, the higher is the percentage of students experiencing complaints. Also, the relationship we found between the number of daily computer working hours and the seriousness of WRULD symptoms expressed as occurrence x duration of complaints (OxD) was in line with previous studies [14]. It was concluded that because of the gradually increasing daily computer time in higher years of studying we observed in our study, also other aspects might play a role like the high study load of the master programme, students' improved commitment and responsibility towards clients and peers in real-life projects, and perhaps also the more tangible financial consequences of their studying. Furthermore, the possible influence of societal changes on RSI problems throughout the 2004-2014 time span are identified like the introduction of loan systems combined with limitations in study time. The impact of the COVID pandemic and related changes in students' lives and - on distance - study is investigated by a small literature study indicating that the prevalence of WRULD complaints increased in some human body locations but reduced in others.

Key findings of Chapter 4

In Chapter 4, a product from the industry with the aim to restore blood flow in people with RSI complaints is introduced together with the assumed underlying alternative physiological mechanism leading to the impaired blood flow and consequently RSI problems. This alternative explanation for blood flow impairment is based on an assumed restriction at the costoclavicular gate - the space between the clavicle and the first rib where the artery and vein enter the upper limb - due to sustained static contractions in the neck muscles resulting from prolonged posture and stress. It is hypothesised that the use of a biofeedback pen providing the user visual feedback on its pinch force by means of a light signal at the pen top would relax the hand, arm and neck muscles and result in an enlarged costoclavicular opening and therewith increase the blood flow in the subclavian vein and artery. Both the suggested underlying physiological mechanism and the effect of the pen with biofeedback on blood flow are evaluated in a physiological experiment with potential users. The level of blood flow was established by taking peak blood velocity and cross-sectional area measurements with echo-Doppler in the subclavian artery in the costoclavicular gate of 13 subjects with RSI symptoms and 24 healthy controls.

The results showed lower blood flow levels in the upper extremities of people with RSI complaints compared to healthy controls, which is in agreement with the alternative explanation as indicated above. Previous studies of Brunnekreef [15, 16, 17] showed reduced blood flow values in the upper limbs of subjects with RSI as well. However, the assumed constriction at the costoclavicular gate was not supported by our findings related to the arterial section. Also the peak blood flow was expected to increase during writing with the biofeedback pen which was not found in our study. Based on the results of the section, peak velocity and peak blood flow after writing with the biofeedback pen for several days, no 'learning effects' could be determined. The expected vascular normalisation due to reduction of pinch force and consequently muscular tension in the arm, shoulder and neck muscles was not established in our study.

Key findings of Chapter 5

In Chapter 5, two RSI preventive design opportunities are formulated based on literature. These are 'Aiming for cognitive relaxation' (besides physical relaxation) and 'Focusing on macro breaks' (with a duration of the order of minutes). The rationale is that while there is consensus on the need of break taking during computer work, imposed breaks can be cognitively stressful especially during more complicated computer tasks and when deadlines loom. Additionally, research [18] shows that, instead of micro breaks, macro breaks need more attention. Two RSI preventive product ideas are introduced based on these insights.

One of the product ideas is an alternative input and pointing device to be used for cognitively low demanding – and possibly even entertaining – computer tasks like executing search queries, looking up words or finding pictures on the Internet. Performing such tasks with an alternative input device may lead to cognitive and physical relaxation. The second product idea is a software application that shows customisable video content during macro breaks. This idea aims at mental distraction from the actual work tasks by means of personalised entertainment.

This second product idea was elaborated into a working digital prototype offering video footage of African wildlife and was evaluated by 10 computer users. Eight out of 10 participants indicated that they experienced a revitalising effect during the work spells after the video breaks. These participants reported to have experienced reduced mental load after the breaks, to have a new mindset, to be more relaxed, to feel more pleasant, to have less need for a large break, and to be less tired in the head. Two subjects indicated not to have experienced a revitalising effect. One reasoning was the need to mentally pick up work after the video breaks, which cost time and created irritation. Although the video watching enabled the user to change working position and to unload working muscles (e.g. by taking the hands off the mouse and keyboard and putting them in the lap), some subjects commented that physical movement, such as walking away from the screen, was still desirable. They felt somewhat bound to the screen and also the lack of relaxation for the eyes was mentioned. These findings have been taken into account in the developed product idea that is subject of Chapter 6.

Key findings of Chapter 6

The idea for the product-service system developed in Chapter 6 encourages computer workers to regularly step away from their screen and to move their body for a few minutes with the aim to prevent RSI and also Computer Vision Syndrome (CVS). The principle is based on drinking water and going to the toilet, which are two strong physiological needs. The user's working time and break time are measured by the sensed mouse movements. The product-service system is communicating through different light patterns on the bottle and motivates the users to take more breaks from their screen work and to keep their hydration levels high. The evaluation by a user group of 13 participants shows that the idea has potential for three quarters of the respondents and slightly more than half would like to use the product in the future. The idea of a break reminding product-service system based on human physiological needs seems to be promising. In addition to physical relaxation, some degree of cognitive relaxation is also expected due to the change of environment and the necessary detachment from the work on the screen. However, the idea needs to be developed further and long term health effects related to WRULD and CVS should be studied.

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Impression of yearly organised massages for students and employees as part of the RSI prevention activities

CHAPTER 8

DISCUSSION

In our current lives in this twenty-first century we usually do not have to deal with life-threatening situations as often as at the beginning of our human existence in historic times. This is especially true for countries with highly developed economies such as North America, Europe, Australia, parts of Asia and New Zealand, where there is usually democratic governance in peacetime. Apart from sad and stressful life events that occur in every human life, and the recent pressure imposed on society by the COVID-19 pandemic, residents of the western world predominantly have the luxury to lead relatively comfortable lives. However, in particular people in these areas experience complaints related to stress and survival strategies while they work with the most advanced digital communication means like it's a matter of life and death. A group of these complaints is the Work-Related Upper Limb Disorders (WRULD) as it is often called in British medical literature, or Repetitive Strain Injuries (RSI) as it is called in the Netherlands e.g., which is the subject of this thesis in the context of young, intellectually and technologically rapidly developing people, the IDE university students.

In this chapter, the research questions as formulated in the Introduction of Chapter 1 are answered based on the studies of this thesis, of which the results per chapter are given in the previous Chapter 7. Furthermore, the relevance of the findings of this thesis for non-(IDE) student populations is discussed. In addition, the implications for the application of the findings is evaluated from different educational perspectives (legislation, university, faculty, educational staff and student). The limitations of the various studies in this thesis are indicated in the respective chapters. In this Discussion, the limitations of the research in this thesis are evaluated in a more general sense. Finally, advice is given for further research.

Why are students Industrial Design Engineering at risk?

In Chapter 7 (section 'Key findings of Chapter 1'), an inventory is shown of the physical, psychosocial and personal risk factors for the onset and exacerbation of WRULD as we know from literature. It is concluded that the study environment and educational programme of IDE contains many aspects that relate to these risk factors. What are these aspects and which are particularly important?

The study activities of IDE students are very attractive and satisfying. New ideas, designs and developments are often a form of self-expression that simultaneously contribute to an ambitious higher social goal. On the other hand, the work of these creative knowledge workers is mentally demanding. Designing is not a linear process but requires converging and diverging thinking when approaching the design challenge with a lot of uncertainty, decision making, user and technological testing and trial and error. The reality is that this comes with a high study load. The working hours per week are the highest compared with other disciplines [1] and the computer is used intensively in this process. In addition to manually drawing and making of physical models and prototypes in the workshop, a lot of knowledge is acquired, and ideas and concepts are created, evaluated and communicated through computer applications. These concern the basic word processing programmes, but also graphical lay-out, visualisation, and 3D CAD programmes, which require high precision.

This intensive use of the computer and related input devices, leads to many sitting hours and a static position of the upper limbs, back and neck and a large amount of repetitive movements of lower arm, hands and fingers. This intensive computer use also requires great effort from the eyes. The workplace in which this happens, at the university or at home, is not always ergonomically optimised, which may lead to awkward working positions. The workplaces at the university differ from study location to study location, are not always adjustable to personal body dimensions and preferences and the home workplaces of students are not always given much attention - due to ignorance and limited financial resources - while used intensively. The latter aspect has become even more relevant in the recent COVID-19 era in which students mainly worked from home.

In addition, students must learn to deal with the strict deadlines in the curriculum. This can be difficult in creative design activities because the time required to get a good idea is difficult to estimate and also the end point of the process is sometimes hard to determine because there is always room for improvement. This can prevent students from giving themselves the time to recover after an intensive period of work, or from scheduling time for physical activities. Also personal risk factors play a role here. The aforementioned self-expression and ambition to strive for a higher social goal might encourage/evoke perfectionism in students.

At first glance, the risk factor ‘Inadequate social support’ seems to play a less important role, because the IDE study contains a lot of group work and there are many contact moments with the staff members that contribute to the feeling of being supported. However, a substantial part of the work still remains to be performed individually, and especially during the lockdowns of 2020 and 2021, there was lack of social support as a result of having to work online from home. More than usual, students ran into problems because of this, for example during their individual graduation project. The student advisors were heavily loaded to meet the students’ interview requests. It is not yet known what the effect was on the WRULD complaints.

In summary, the author of this thesis is of the opinion that especially the creative nature of the IDE study in combination with the strict and frequent deadlines of the curriculum, can cause planning problems, stress and work pressure, and might therefore play an important role in the development of WRULD complaints. We see confirmation of this in the fact that the other creative TU Delft study, Architecture, also struggled with relatively high numbers of students consulting the SGZ because of their complaints or even applied for medical statements. Other important aspects related to risk factors that are particularly present in the IDE curriculum are the required precision in many computer tasks, the complex nature of designing and the high ambition of students when it comes to creating personal designs. Stress inducing societal aspects like the introduction of loan systems combined with limitations in study time is assumably counter effective in reducing WRULD problems for students more in general, because of the related time pressure and financial worries.

To what extent is this population at risk?

Chapter 2 shows that the percentage of students experiencing WRULD complaints - including eye problems - in the academic years 2000/2001 and 2002/2003 were respectively 61% and 59%. These results are comparable to those of our large study of Chapter 3, indicating prevalence rates between 53% and 61% (average of 57%) in the five academic years studied during the period 2004 to 2014. In both studies prevalence rates are higher among students who have been studying for longer time than among students who have just started studying.

Not all complaints are of similar severity. A majority of the respondents who report complaints have less serious complaints of 1-50 hours per year. The percentage very serious complaints of > 800 hours per year is highest in our last 2013/2014 measurement also compared to the percentages found in our previous measurements on the academic years 2000/2001 and 2002/2003.

Does this mean that we should regard WRULD as a fact of life, that little has changed over time or that the picture has even deteriorated? As we saw a clear aggravation of WRULD (prevalence, occurrence, duration and the two alternative measures for the seriousness) in the last measured academic years. We concluded in Chapter 3, that this could not only be explained by the steady increase in reported computer time over the academic years, and it was striking that this trend ran parallel with the introduction of loan systems combined with limitations in study time. The author of this thesis is of the opinion that in addition to the increase in computer time, these major societal changes have had an important impact on the stress level and consequently the severity and magnitude of WRULD problems amongst students.

In Chapter 2 an overview is given of the percentage of students consulting the SGZ for WRULD-related medical advice and the reduced study capacity and related study delay of students with more severe complaints reflected in the medical statements issued by the SGZ during the first years of the millennium. These figures, which were also registered per faculty, were no longer available in later years due to a changed registration system at the SGZ. However, recent personal communication with one of the current SGZ doctors [2], indicates that she does not see many students with WRULD complaints during her consultation hour and that she also issues few medical certificates. Although not all students with WRULD complaints will visit the SGZ doctor because they choose to consult their home doctor or physiotherapist, this may be an indication that there are fewer students with such serious complaints that they need medical advice and possibly financial compensation based on a medical statement as compared to the first years of the millennium. Recent personal contact with one of the student counsellors of TUDelft [3], involved with financial assistance from the Profiling Fund TU Delft for students having a study delay due to 'unforeseen circumstances', also indicates only a few requests per year for financial compensation because of WRULD problems. A caveat must also be made here. As mentioned in Chapter 3, the regulations for student finance have become stricter compared to the first years of the millennium and students have had to pay much more study-related costs themselves or had to take out loans. Compensation rules have also changed. A medical certificate is still required, but before TU Delft can compensate, a one-year extension of the governmental grant by DUO [4] must first be applied for, which is often also a loan. This can prevent students from applying for compensation from TU Delft.

Nevertheless, as shown in Chapter 3 and further described in Chapter 7, the results of our last measurements in the academic year 2013/2014 indicate a substantial percentage of students experiencing very serious complaints of > 800 hours per year and with the most serious complaints of > 1600 hours per year, even reaching absolute numbers of respectively 174 and 105 students. The consequences for these groups in terms of wellbeing, productivity, absence, study delay or even requests for financial compensation or dropping out of studies are not known, but this must have had a major impact on their student life and progress.

We do not have such data from more recent academic years. Therefore, also the consequences are unclear of the most recent societal changes in students' lives, i.e. the WRULD risk factors and related figures during the working from home episodes of the recent COVID-19 era. We assume that it caused additional fear and worries and therewith additional stress. The previous mentioned lack of social support when working in (physical) isolation, might have had a negative impact on WRULD as well. However, some studies show that the prevalence of WRULD complaints increased in some human body locations but reduced in others [5, 6, 7, 8] as we have seen in Chapter 3. A possible explanation of this decrease of complaints in some body regions could be that working from home makes it easier to take breaks at self-chosen moments. In addition, people may feel more free to change their working posture or choose exercise and relaxation activities based on their own preferences, without the social pressure of others (students/teachers) being present.

What are promising prevention possibilities?

In our study of Chapter 2 on WRULD among IDE students in the academic years 2000/2001 and 2002/2003, we observed an increase in students' daily computer working hours, accompanied by a decreased prevalence. The conclusion was drawn that the IDE WRULD prevention programme may have contributed to the reduction of the amount of complaints. In our large study on WRULD between 2004 and 2014 of Chapter 3, we also found that WRULD problems amongst IDE students ameliorated during the first three or four academic years of study, despite the students' increasing daily computer working hours. The positive effect of the WRULD prevention programme in this perceptive, is supported by the study on WRULD among the working population of vd Meulen [9], indicating in the same time frame as well a reduction of occupational diseases related to the upper extremities, as shown in the Figures 3.1 and 3.2 of this thesis. The structural attention for work-related risk factors and prevention measures in the professional sector has been identified in this study as a possible cause for this decline. A similar positive effect of the attention for the WRULD topic as provided by the WRULD prevention group, is visible in our studies. Therefore, the particular prevention activities of this programme based on the available knowledge on risk factors and etiology will firstly be more detailed and discussed in this section on promising prevention measures.

The WRULD prevention programme in the IDE curriculum

For first year IDE students, the programme starts with a WRULD prevention lecture by the Students' Health Service (SGZ) and is aimed at providing information on WRULD and related risk factors and creating awareness to prevent complaints. The physical and psychosocial risk factors are explained and advice is given on how to properly set up a workplace, on a how to avoid awkward postures during computer work and how to organise variety in work activities and time for (active) relaxation to be able to get back to work with a fresh look and a new perspective. The importance of a stimulating work environment and social support, especially when deadlines are approaching is explained. Furthermore, the origin and positive and negative effects of stress are discussed and the relevance of a good work planning and setting achievable goals and boundaries is highlighted. The influence of personal risk factors like perfectionism and overcommitment is also explained and it is emphasised that a good physical condition can protect against the development and worsening of complaints. Despite the fact that usually not many severe complaints occur in this group of younger first year students, it is already pointed out that in the event of experiencing more serious and limiting complaints during their study, it is important to talk to the student advisor to discuss possible adjustments to the study programme and to visit the SGZ doctor or students' own family doctor to have the nature of the complaints examined. This is to prevent students from waiting too long before taking action and to offer them a clear approach what to do. Students are reassured by explaining that the mild complaints that occur most often in this student group of first years of study, require some time but will pass by themselves when the risk factors are considered more closely and are reduced. It often concerns complaints as a result of a period of intensive computer use and muscles and tendons need time to recover.

To place the information in a realistic context, an experience expert student tells a personal story about the origin and course of his or her complaints and what was needed to reduce, learn how to live with or to get rid of the complaints.

In the practical part of the first year prevention programme, students receive information in a group from two Cesar therapists while sitting on adjustable office chairs and discussing and experiencing an ergonomically well-designed workplace. It is explained and interactively demonstrated how to optimise their workplaces (table, chair, screen position, feet position and input devices) according to their individual body dimensions. To exemplify this, Figure 8.1 shows the user-friendly application on the former IDE RSI prevention website by which the personal ideal workplace settings could be determined by entering

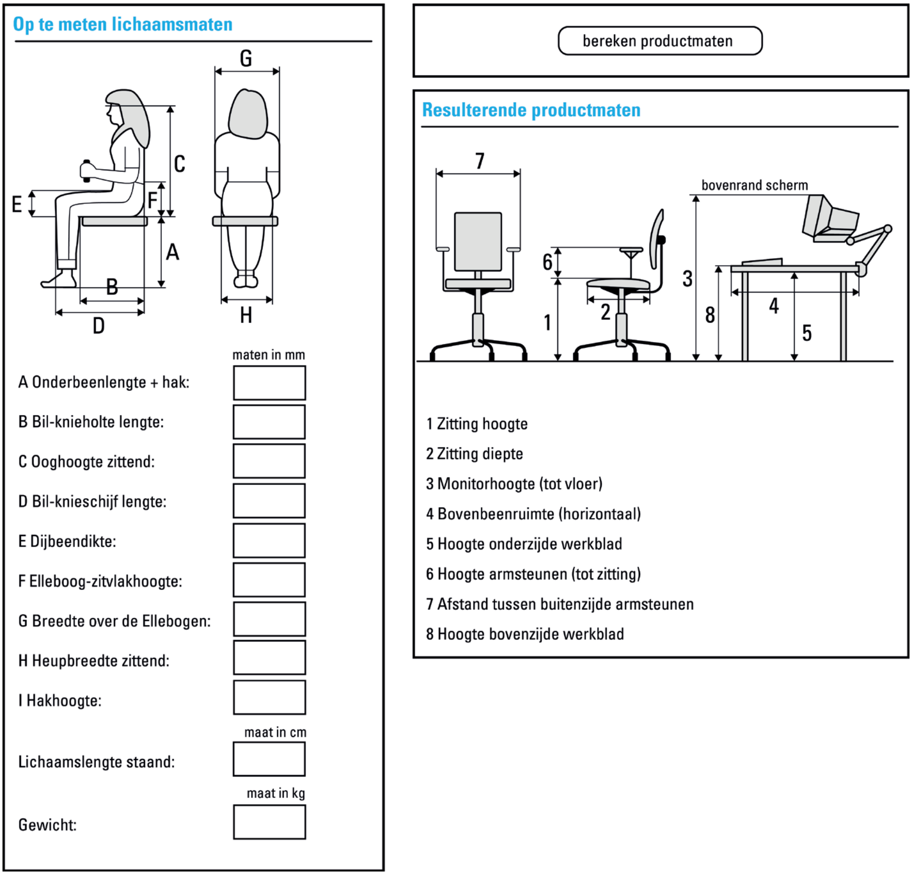


Figure 8.1. Anthropometric measurement form for a comfortable workplace. This application was available digitally through the former IDE RSI prevention website. Molenbroek JFM, Lok H, Dekker MC, 2008 [10].

the individual body measurements. Furthermore, the Cesar therapists explain how to recognise and reduce muscle tension at the workplace by making the tension visible with myofeedback, and which exercises can be done to relax intensively used muscles in the back, neck, shoulders and arms. During this prevention session, students can also ask advice in case of (beginning) complaints.

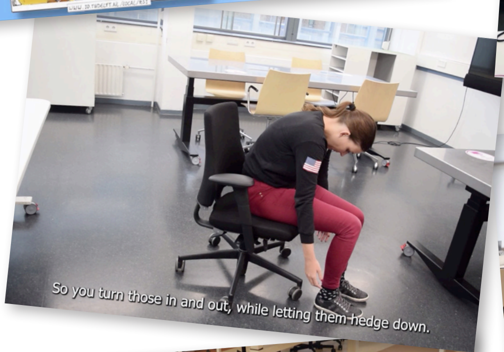
Another practical WRULD prevention session is organised to second year students during a computer practical. In this practical, students can consult the Cesar therapists at a time that suits them while they are working in front of the computer. They can ask the therapists WRULD-related questions about, for example, work pressure, relaxation exercises, muscle tension (which can also be measured), working method, sitting position, way of moving, their (home) workplace, input devices and what to do in case of WRULD complaints. In this setting things can be easily shown and explained. In case of serious complaints, a referral can be made to the doctor or psychologist of the SGZ, the general practitioner, physiotherapist or to the TU Delft psychologists [11].

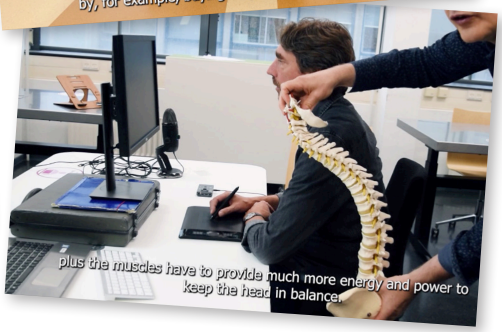
During the COVID-19 lockdowns of 2020 and 2021, the previously described face-to-face prevention sessions in the IDE curriculum were replaced by an online WRULD prevention movie and the possibility to consult the Cesar therapists online (see page 163).

One more activity has not been able to take place during the lockdowns, but is usually a regular part of the programme. This concerns the massage moments, organised two times in the academic year. Students and staff members can register for a chair massage or they are massaged by one of the masseurs who spontaneously visit their workplaces. Besides the fact that the massages have a revitalising effect, people become aware of tension present in the body that in the long run might lead to WRULD complaints (see page 154).

In former years, sport and relaxation workshops (SPRT) have been organised for IDE students of all years and employees to create or refresh awareness for WRULD (see pages 166 and 167). During a few days in the spring, a diversity of activities was offered to students and staff in and outside the faculty building, consisting of e.g. table tennis, badminton, football, playing frisbee and rugby. Workshops were offered in e.g. tai chi, capoeira, salsa dancing and relaxation exercises, various types of massages were given such as foot massage and chair massage, and it could be learned how to give each other a relaxing chair massage. These vibrant and active days at the faculty were not only intended to cheerfully draw students' attention to the importance of variety, exercising and relaxation of body and mind. Cesar therapists and a doctor from the SGZ were present to answer questions from students and employees related to the prevention and development of WRULD complaints. The SPRT took place from 2003 to 2013, after which it unfortunately discontinued because its organisation became too time consuming. The IDE RSI prevention website that had meanwhile been used TU Delft-wide and beyond, is also

Impression of the RSI prevention movie, co-created by the Cesar therapists Jeroen Hutten and Cees Verhoeven and the author of this thesis, and used during the COVID-19 lockdowns of 2020 and 2021 to inform students online





no longer available because maintenance was taking too much time. The aforementioned WRULD prevention movie contains a lot of information that was previously communicated via this website. The other parts of the programme described in this section have had a recurring character up to now.

Initially, the IDE prevention programme was set up for IDE students, but it soon became apparent that it was important to also reach the IDE staff to provide them insight into the phenomenon and enable them to better respond to students with WRULD complaints and to advise them on referral. In addition, they were also interested in the information about WRULD because of their own health and therefore involved in the programme through the 'open' activities - components that were not integrated in particular courses -, such as the SPRT, massage moments and staff-specific lectures and sometimes even joined the WRULD consults provided by the SGZ doctor and the Cesar therapists. The author of this thesis believes that the activities organised by the WRULD prevention group may in fact be relevant and applicable not only to students and staff of the Faculty of IDE, but to many different groups of student and adult computer workers in education and professional environments.

Products and product-service systems in WRULD prevention

The aforementioned activities of the WRULD prevention group are organisational interventions aimed at raising awareness and changing behaviour to improve health and comfort of students and also staff members. It is important that the advises broadcast to prevent complaints actually take root in the practice of daily studying and working. Therefore, repetition and variety in the ways of spreading the message is important. This can also be done through products or product-services systems that are more permanent present in the computer worker's working environment. Examples of these are presented, discussed and evaluated in this thesis. Although some of these product ideas have been tested exclusively with student participants, the interventions are also suitable for users other than students as described in the chapters concerned.

The aim of the biofeedback pen as investigated in Chapter 4a and 4b is to reduce muscle tension and therewith increase blood flow. Although the effect of the product could not be determined by us, biofeedback can be a promising direction to teach the user to better self-regulate tension. Peper et al. [12] described the benefits of a training programme for preventing WRULD including electromyography, and the positive effects of biofeedback on e.g. muscle relaxation, stress and anxiety, are indicated by Zafeiri et al. [13]. Biofeedback makes the user aware of internal body processes on the basis of which can be decided to adjust behaviour and habits. For a shorter or longer period of time, depending on how quickly the user learns to better recognise body signals, this can be a support and reminder. It can also be left unused for a while and picked up again in challenging times.

Disrupting the work-related static load and repetitive movements by taking regular breaks is another measure to prevent WRULD as was explained in Chapter 5 and 6. However, taking longer breaks is not always possible, or not always socially desirable (or at least perceived as such) or people often do not allow themselves, in particular when deadlines are looming. For this reason, a number of interventions in the workplace itself have been researched, developed and evaluated in this thesis. An important finding here is that it is essential that physical relaxation and cognitive relaxation go hand in hand in particular in more complex computer tasks. In addition, people sometimes need a helping hand to break free from the mentally demanding, attractive and attention-absorbing screen work. In order to create a natural transition and not additional stress because of imposed breaks, considering interventions based on human physiological motivation is a promising direction.

An organisational intervention together with an ergonomic product or product-service system as indicated above, can be a strong combination. Robertson et al. [14] investigated the effects of an office ergonomics training combined with a sit-stand workstation on musculoskeletal and visual discomfort, behaviours and performance. It was suggested that training plays a critical role in mitigating symptoms, changing behaviours and enhancing performance. The author of this thesis is also of the opinion that creating awareness and providing information about WRULD as done e.g. in the SGZ lecture for first year students and the two practical prevention sessions for first and second year students, is essential in prevention and will be supportive in the effective use of ergonomic products in general and of the ideas discussed in this thesis that remind the user of healthy computer working.

Implications for application

This thesis has set out the prevalence and seriousness of WRULD complaints among university design students and shows that they are present to a considerable extent in the investigated time frame. The Faculty of Industrial Design Engineering at Delft University of Technology is not unique in this perspective. The Introduction section of Chapter 6 describes WRULD prevalence rates including eye problems of professional computer working populations. The studies concerned show a wide spread of percentages including values that are (much) higher than the 57% we found. The Introduction section of Chapter 3 indicates the health effects of computer-related activities of young adults like US college students [15] and Swedish vocational school, college and university students [16]. Smit et al. [17] conducted a questionnaire-based research into WRULD complaints in students of Dutch secondary professional education, higher professional education and university education from various disciplines (agriculture, nature, technology, health, economy, law, behavior / society, language / culture and education). WRULD complaints as a result of computer use occurred in particular in higher professional education (71%) and university education (76%). Respectively 7 % and 15% of the participants indicated that they experience '(very) much'

Impression of the organised Sport, Pause and Relax Treat (SPRT) activities at the faculty


6th May
7th May
take a break, prevent RSI
Sport Pauze & Relax Treat
S.P.R.T.
8th May
In addition:
May 6–8 2013 at IDE Faculty
rsi.io.tudelft.nl/sprt
SPRT
15

nuisance from these complaints. Similar to our studies, the WRULD complaints appeared to occur mostly in the higher years of studying. As indicated in the section 'What are promising prevention possibilities?' the author of this thesis is of the opinion that the developed prevention programme and the proposed ideas for product and product-service systems may be relevant and applicable to many different groups including the student and adult computer workers in education and professional environments as indicated previously.

In addition, I will present some advices for the application of the knowledge obtained during this dissertation related to education.

Legislation

Although somewhat out of the scope of this thesis, it is good to know that there is legislation on European level for the minimum safety and health requirements for work with display screen equipment as stated in the Council Directive 90/270/EEC [18]. In the United States, the Occupational Safety and Health Act [19] requires employers to comply with hazard-specific safety and health standards as issued and enforced by either the Department of Labor's Federal Occupational Safety and Health Administration (OSHA), or an OSHA-approved State Plan. Both this directive and act are described in Chapter 5 in the section 'Legislation, standards and recommendations related to rest breaks in computer work'. In the Netherlands, we have the Occupational Health and Safety Legislation [20, 21] on the requirements that work equipment must meet and rules that are mandatory for both employer and employee. Article 5 [22] of the 'Arboregeling' deals with computer screen work, including requirements that equipment and furniture, the layout of workplace and software must meet. Employees also have their own responsibilities, e.g. to organise an ergonomic workplace and facilities and to ensure that the amount of computer work during leisure time does not result in WRULD complaints. Many of these indicated regulations in the Netherlands, also apply to students. However, much of this regulation is still broadly defined or no longer fully applicable to the rapidly advancing technological developments. Therefore, the most important aspect in these regulations is perhaps that the computer worker also has responsibilities for good working conditions and therefore he or she must have acquired sufficient knowledge. The advice I would like to give the government based on my research is not to introduce stricter measures regarding study finance and study duration. In this respect, the intention to re-establish a basic grant for higher education in 2022/2023 is a positive development. In addition, it would also help if the financial compensation schemes for students with serious WRULD complaints could be relaxed.

University

My advice to the university is to strengthen communication between the student advisors (or nowadays called 'academic counsellors') who are consulted by students with WRULD complaints and associated study delay, the student doctor who can investigate the complaints and issue a medical certificate in serious cases, and the student counsellor who can support the student in applying for a study extension and financial compensation arrangements. In the case of some WRULD complaints, also communication between these parties and the TU Delft psychologists is important. Furthermore, a digital platform must be revived, to inform students and staff on comfortable and healthy computer working and to ensure they will know what to do in the event of complaints. In addition, good communication and cooperation between the superior of the staff member, the Health, Safety and Environment Advisor, and the company doctor is important for staff employees.

Faculty

I would recommend continuing to distribute knowledge about WRULD risk factors and solutions for healthy computer working to students and staff. In addition, offer postponements options for students who experience time pressure due to WRULD complaints. Student advisors play an important role in assessing the problems and composing an adapted study programme in consultation with the student. Furthermore, it would be good to regularly inventory for the entire curriculum in which courses and at what times deadlines and peaks in workload occur, often associated with much required computer hours, in order to limit the workload through favorable scheduling. And lastly, make use of the available expertise within the section Applied Ergonomics and Design of the Faculty of IDE in selecting office furniture and accessories for students and staff members.

Course coordinators and staff members

Course coordinators should be encouraged to set achievable learning goals in relation to allotted study time for a course. It must be looked at how the course can be organised as efficiently as possible for the student to achieve these goals and to prevent the course from becoming an accumulation of assignments due to the ambitions of the teachers. Coordinators and staff members who participate in a course and have contact with students must be aware of how students can be referred in the event of complaints.

Students

Students must be well informed about healthy computer working, as is also offered in the WRULD prevention programme (personalised workplace, good planning, enough breaks and relaxation, enough rest, variety of activities, exercise, etc). Although the costs are relatively high, try not to cut on workplace items such as a good office chair, input devices and laptop holder. Take measures with regard to the risk factors in the case of starting complaints and if complaints worsen, make these known to group mates, the relevant staff members, course coordinator, student advisor and, if necessary, the student doctor, general practitioner or TU Delft psychologists.

The author of this thesis is of the opinion that it will be difficult to rule out WRULD complaints. However, if we organise the aforementioned insights properly in the future, we can prevent students from having to apply for a long-term study extension and related financial compensation or, as happened before, even prematurely having to stop their study.

Lessons learned

Fortunately, the development of chronic complaints does not occur too often in the studied student population. However, over the course of 20 years of research, the author of this thesis has regularly spoken to young people with - a history of - chronic complaints. Although this is just a personal experience, it was remarkable that after a long search and many treatments, these patients often found benefits in a treatment with a psychological basis. Also in personal contacts with physiotherapists this shift in WRULD treatment was noticed over the years from a mainly physical approach to a more psychosomatic approach. This personal experience is supported by literature. An example of this more holistic view in treatment is the cognitive behavioural therapy [23] as described in Chapter 1. Another far-reaching and fascinating example is John Sarno's book "The Mindbody Prescription" [24] on the influence of the subconscious mind on the development of unexplained musculoskeletal pain disorders, including WRULD. It is believed that the brain distracts patients from suppressed feelings through pain. The described treatment focuses on the mind rather than the aching body, assuming the pain is the result of unconscious emotions like anger and worry. An inspiring patient experience [25, 26] based on these insights is the story of the down to earth journalist and children's book writer Anna Woltz. She suffered from pain in her arms, shoulders and back for a long time that prevented her from sleeping, was very skeptical about Sarno's book, but got rid of these complaints by thinking about what she was angry about and acknowledging it.

Limitations of the study and future research

The limitations of the various studies in this thesis are indicated in the respective chapters. More generally, I regret that we did not have the ability and capacity to maintain the measurements as lastly performed in the academic year 2013/2014 up to the present including the period during the COVID-19 lockdowns. It would be interesting to know whether the worsening of the WRULD problems would have continued, stabilised or indeed diminished as the SCG doctor and student counsellor seem to have observed. The prevalence and severity of the complaints and the concerned body locations during the special period of the lock downs in 2020 and 2021, would also have provided valuable insights into the effects of the COVID-19-associated societal changes.

In our first study, covering the years 1999-2003, in addition to the magnitude and severity of the complaints, we also analysed the data available from the questionnaires on students' self-reported causes for their complaints, as can be found in short in chapter 2.

It would be worthwhile to also analyse the comparable and available data from the larger 2004-2014 study as described in Chapter 3, in order to compare these outcomes with our observations and to sharpen our vision on the most relevant risk factors as described in this thesis.

Concerning the product ideas presented and evaluated in this thesis, these are in the first place expressions of underlying theories and insights, more than completed product and product-service systems. The idea of the video-supported macro break has probably been overtaken by the current ubiquitous availability of movies on a large variety of topics on smartphones, tablets and laptops and accompanying algorithms for a personalised selection, although using it meaningfully and appropriately for relaxation purposes can still be a challenge. The Break Bottle idea can be a powerful mean to achieve or maintain healthy break behaviour during computer work. The evaluation with users revealed which aspects still need to be further developed to be able to determine the likelihood of success.

As has probably become clear from this thesis, according to the author, the greatest strength of WRULD prevention lies in raising awareness and informing the computer user about this topic. The WRULD prevention programme based on these aspects has been developed in the context of a user group vulnerable to WRULD. However, the knowledge gained is applicable to many other educational and professional groups.

Over the years, the IDE WRULD prevention programme has been continuously adapted to societal changes, medical insights and rapidly advancing technological innovations in computer equipment, input devices, accessories and office furniture. Optimisation of the programme according to the current and future developments deserves attention, as does the scientific substantiation of the effects of programme components. This will not only prevent WRULD complaints, but will also increases the feeling of comfort and well-being of computer workers.

An important advice for healthy computer working adopted in this thesis is to alternate work with physical and relaxation activities, as also illustrated by the events like the Sport, Pause and Relax Treat (SPRT) and the biannual massage moments of the WRULD prevention programme. The organising WRULD prevention group was often asked by students and staff whether the relaxation and exercise activities could be present throughout the year. In retrospect and considering the literature written on the subject over time, the author of this thesis has the opinion that these more permanent prevention measures of integrating information, relaxation and physical activity into the curriculum are a good way to prevent and counter WRULD complaints. However, creating physical and relaxation activities in and around the workplace can also be challenging as we experienced when organising the SPRT activities. For example, the privacy aspect is important. There is often some feeling of embarrassment to participate in sports, dance or relaxation activities in the presence of fellow students and staff members in the work environment. It may very well be that social pressure, not wanting to withdraw from the workflow, also plays a role here. Outdoor exercise activities or, activities in a room out of sight of the public are in this respect more favourable than indoor organised activities in public. This can at the same time meet the requirement that the activities should not be disruptive to people who are concentrated at work. In summary, it seems to be a good idea to bring these activities to the people at work and being able to move and relax right away is appreciated and valuable to unload muscle tension due to intense screen work, to cognitively 'switch-off', to socialise and to return to work revitalised. Further research into the exact type of activities, their effects and on how they can best be offered seems to me a very interesting and useful future research and design assignment, which can also be performed in a different professional or educational user context.

In conclusion, this thesis has set out the prevalence and seriousness of WRULD complaints among university design students and shows that they are present to a considerable extent in the investigated time frame. The author of this thesis is of the opinion that the developed prevention programme and the proposed ideas for product and product-service systems, all supported by literature, may be relevant and applicable to many different groups including student and adult computer workers in education and professional environments to realise healthy computer working.

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SUMMARY

The focus of this thesis is on Repetitive Strain Injuries (RSI), also called Work-Related Upper Limb Disorders (WRULD), amongst university students. From the end of the last millennium, students started to report WRULD complaints to the student advisors of the Faculty of Industrial Design Engineering (IDE) at Delft University of Technology (TU Delft) and to the student doctors of the Students' Health Service (in Dutch 'Studentengezondheidszorg' abbreviated SGZ). These numbers of reported complaints reached a substantial level in the first years of the current millennium, leading to the activities described in this thesis based on the following questions:

> Why are students Industrial Design Engineering at risk?
> To what extent is this population at risk?
> What are promising prevention possibilities?

Chapter 1 outlines three etiological models (Impeded blood circulation, The neuromotor noise theory and Pain reception) of which the author thinks they represent plausible explanations for the development of WRULD complaints. Moreover, the involved physical, psychological and personal risk factors for the onset and development of WRULD as reported in literature are presented and discussed. It was concluded that the study environment and the educational programme of IDE contain many aspects that relate to these risk factors. Furthermore, this chapter introduces the composition, aims and activities of the WRULD prevention group, which was established by the IDE Educational Director in 2000 in response to the rise of complaints, and which is still active today. The activities organised by this prevention group are based on the available and constantly developing scientific insights about the origination mechanisms and risk factors of WRULD.

Chapter 2 presents the number of TU Delft students who visited the SGZ doctor in the period 1999-2003 with regard to WRULD complaints. The amount of study delay as a result of WRULD over the same period is also shown on the basis of medical certificates issued by the SGZ for students with serious complaints, which qualify them for extra study time and in some cases also financial compensation for their delay. From these figures of TU Delft students it became clear that WRULD complaints occurred most at the Faculty of IDE and secondly at the Faculty of Architecture. In addition to the human impact, there was also financial loss due to students not being able to study at a regular pace. These are presented in this chapter, broken down into the individual costs for the student, and the costs for the university and government.

This chapter also introduces the longitudinal survey on WRULD complaints amongst IDE students. Results of these measurements in the academic years 2000/2001 and 2002/2003 show WRULD prevalence rates of 60% on average and most complaints occurred in the wrists, shoulders and the neck. Students of higher years of studying experienced most complaints. Severity results based on the occurrence times duration showed that most complaints were experienced for less than 100 hours per year. In the academic years 2000/2001 and 2002/2003, however, 4% and 9% respectively of the complaints group had very serious complaints lasting more than 800 hours per year. The activities organised by the WRULD prevention group for students – and to a lesser extent IDE employees - aimed at reducing WRULD risk factors and complaints, are described in this chapter.

The largest study of this thesis is included in **Chapter 3** and is an extensive follow-up survey concerning data of 2254 IDE students collected over a 10-year period (2004-2014). The percentages of students reporting WRULD vary between 49% in the first year of studying and 75% in the fourth year of studying, resulting in more than half of the students (57%) experiencing WRULD complaints. The duration, frequency and seriousness of these complaints differ greatly. A decrease in the prevalence, occurrence, duration and two alternative measures for the seriousness of WRULD have been observed from the first (2004/2005) to the third (2008/2009) or fourth (2010/2011) recorded academic year followed by an increase of these values to the fourth or fifth academic year (2013/2014). Limiting financial and study time factors may have played a role in this increase. In agreement with previous studies amongst adolescents and young adults, structural attention to prevention and risk factors as organised by the WRULD prevention group, seems to be effective in reducing the prevalence and severity of WRULD.

Also in this extensive study, the less severe complaints of 1-50 hours per year are seen most, i.e. by 58% of the respondents who report complaints. In the last investigated academic year 2013/2014, the highest percentage of students experiencing very serious complaints of > 800 hours per year was found (15%) and also the highest percentage of students experiencing the most serious complaints of > 1600 hours per year (9%). This measure for the seriousness of the complaints (expressed in number complaint hours per year) and also a second severity measure used (limitation of daily activities) show highest scores in students who are studying in their 5th/6th/7th year. Relations were found between the number of daily computer working hours and the prevalence as well as the number of computer working hours per day and the seriousness of complaints.

In the course of the years, many products have been developed with the aim of preventing or reducing WRULD complaints. One example from the industry is presented and evaluated in **Chapter 4**. It concerns a biofeedback pen providing the user visual feedback on its pinch force by means of a light signal at the pen top, that would hypothetically relax the hand, arm and neck muscles and result in an enlarged costoclavicular opening and therewith increased blood flow in subclavian vein and artery. An experiment in which blood flow was recorded in 37 participants showed a lower subclavian arterial peak velocity in subjects with WRULD complaints compared to complaints-free subjects. However, the blood flow normalising effect of the pen could not be established in this experiment. Limitations of the study such as the duration of the experiment are discussed.

Two other WRULD preventive product ideas created in an IDE master student's graduation project, not only focusing on physical but also on cognitive break taking during computer work, are presented in **Chapter 5**. The idea of a software application realising video-supported macro breaks is evaluated by means of a user test with 10 participants. The results indicate that after the video breaks most users experienced a revitalising effect during their work and that the application was regarded as cognitively relaxing and productivity enhancing. However, the potential WRULD-related health effects and productivity implications have to be further investigated in future research with more elaborated concepts.

The product-service system described in **Chapter 6** is developed in another IDE student's master graduation project and is based on two human physiological needs, drinking water and going to the toilet. This smart bottle reminds its users to drink more water and to refill the object when it is empty aiming users to keep their hydration levels high and take regular breaks from their screen work. The idea has been evaluated by 13 participants, has potential according to a majority of these respondents and revealed the aspects that need to be further developed in order to determine the likelihood of success including long term health effects.

The ergonomic products and product-service systems as designed, evaluated and discussed in this thesis can form a strong combination with organisational awareness and information programmes such as the WRULD prevention programme as described in this thesis. This prevention programme as presented in this thesis, and the proposed product ideas of Chapters 5 and 6 are mainly focusing on the prevention of complaints and worsening of relatively mild complaints. The author of this thesis has the opinion that more permanent prevention measures as integrating information, relaxation and physical activity into the workflow are a good way to prevent and counter WRULD complaints in the university environment and beyond.

This thesis has mapped the prevalence and seriousness of WRULD complaints among university design students and shows that they are present to a considerable extent. It also provides insight in risk factors and origination mechanisms based on existing literature. As in many other work and educational environments, these risk factors are present at the Faculty of Industrial Design Engineering of Delft University of Technology. The thesis shows that prevention measures as offered by the WRULD prevention group described in this thesis are useful. Optimisation of the programme according to the current and future societal changes, medical insights and technological developments deserves attention, as does the scientific substantiation of the effects of programme components. This will not only prevent WRULD complaints, but will also increase the feeling of comfort and well-being of computer workers.

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My special thanks go to the Dutch RSI association (RSI-vereniging in Dutch). I was able to make grateful use of your well-maintained and informative website and learned a lot from the up-to-date lectures and activities you organised annually during the thematic days for people with RSI complaints and those involved in the subject.

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ABOUT THE AUTHOR

I was born on January 3rd 1965 in Delft, the Netherlands. After completing secondary school at the Montessori Lyceum in The Hague, I studied Industrial Design Engineering at the Delft University of Technology (TU Delft). I became most enthusiastic about design assignments with a human centered, dynamic and technical character. Examples of these were the second year toy cart design project for children (in Dutch 'vliegende hollander') and my graduation project in 1990, a design for breathing equipment used by the fire service, carried out within TNO Product Centre (the Netherlands Organisation for Applied Scientific Research) in Delft, in close cooperation with the Rotterdam fire brigade and Dräger Ltd in Lübeck, Germany.

After obtaining my Master of Science (ir.) degree, I worked at Ninaber/Peters/Krouwel (NPK) design office in Leiden, the Netherlands, where I was involved in concept generation, design engineering and creating prototypes for food packaging, medical equipment, laboratory furniture and equipment for scientific research.

At General Electric Plastics in Bergen op Zoom, the Netherlands, I subsequently worked as industry developer of injection moulded thermoplastic parts combined with electronics. Within this setting, I investigated application areas, technical feasibility, sustainability and cost aspects in collaboration with manufacturers and suppliers and created product concepts for clients.

In the last years of the previous millennium I was independent design consultant and later partner in the design consultancy SOLÉ design services, and worked on various consumer products like computer housing and baby buggies and professional projects as the interior of a research flight simulator (SIMONA), roller coaster coaches, and earthquake rescue equipment.

Because of the highly ergonomic nature of the SIMONA project, I came into contact with the section Applied Ergonomics and Design of the Faculty Industrial Design Engineering of TU Delft again. This has resulted in an appointment as assistant professor from 2000 until now, in which I have been involved in education and research.

In this position, I worked on the DINED database (www.dined.nl) which is an application enabling users to browse through anthropometric datasets to obtain insight in variation of human body dimensions and shapes. Johan Molenbroek, founder of the DINED database, has been working on collecting the data for a long time. Together with him and student assistants, we worked on making the data accessible via the DINED website. In 2014 we received The Dutch Data Prize issued by Research Data Netherlands (RDNL) because of the website's accessibility for a wide audience and the care taken in collecting, describing and unlocking the set.

I also coordinated together with Johan Molenbroek the European Socrates/Erasmus project GENIE (Gerontechnology Education Network in Europe) concerning the cooperation between 42 institutions of higher learning (social sciences, design, ergonomics, engineering, medicine, nursing and physiotherapy) from 17 European countries to improve the participation, integration and independence of the ageing people by using technological developments and opportunities.

In addition, I founded the RSI prevention group in 2000 that I coordinate to date and conducted the RSI-related researches as described in this thesis.

In education I fulfilled different roles in various courses ranging from design coach, ergonomic expert, graduation mentor or chair and course coordinator. At the moment I am coordinating the large master course Advanced Concept Design (ACD). The real-life assignments are co-created by the coordination team and a partner organisation (a company, research group or semi-governmental body). This conceptualisation course has a strong focus on integration through the areas of expertise Culture, Ergonomics, Technology and Visualisation supporting the Concept Design project.

I'm married with René van Egmond and we have three wonderful children.

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