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Chronic stress and the skin barrier: the role of chronic stress in the recovery of the stratum corneum

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Abstract

Introduction. Psychological stress, especially when it is chronic, can lead to immunological consequences and serious health issues. Measuring the rate of the skin barrier recovery serves as objective tool to quantify the healing process of the skin, which is one of the immunological responses of the body. The present study investigates the role of chronic stress in wound healing and skin barrier integrity.

Methods. The sample consisted out of n=34 female participants between 18 and 35. The chronic stress, the present stress and the mood was assessed using questionnaires, while their skin barrier recovery (SBR) and skin barrier integrity (SBI) rate was calculated from transepidermal water loss data post to the tape stripping method.

Results. The study found no evidence for a correlation ($r = -.18$, $p = .31$) between chronic stress and SBR, only 3.3% of the variation in SBR were predictable from chronic stress in a linear regression analysis, leading to the rejection of the hypothesis that chronic stress has an effect on SBR. Two explorative analyses examining the mediating effects of mood and the moderating role of present stress did not yield significant models. The secondary question, exploring the relationship between chronic stress and SBI, revealed no evidence for a correlation ($r = .15$, $p = .39$), only 2.4% of the variation in SBI were predictable from chronic stress, suggesting that, within the present sample, chronic stress has no significant effect on SBI.

Discussion. Theoretical and methodological explanations for the unexpected results against the background of the known literature are given. Furthermore, implications for future research and the relevance of the topic are discussed.

Key words: chronic stress, skin barrier recovery, skin barrier integrity, transepidermal water loss, mood, health

Zusammenfassung

Einleitung. Psychologischer Stress, insbesondere wenn er chronisch ist, kann zu immunologischen Folgen und ernsthaften Gesundheitsproblemen führen. Die Messung der Regenerationsrate der Hautbarriere dient als objektives Instrument zur Quantifizierung eines Teils der immunologischen Reaktion. In der vorliegenden Studie wird die Rolle von chronischem Stress bei der Wundheilung und der Integrität der Hautbarriere untersucht.

Methode. Die Stichprobe bestand aus n=34 weiblichen Teilnehmern zwischen 18 und 35. Das chronische Stressniveau, der gegenwärtige Stress und die Stimmung wurden mit Hilfe von Fragebögen bewertet, während die Regernationsrate der Hautbarriere (SBR) und die Integrität der Hautbarriere (SBI) anhand von Messungen des transepidermalen Wasserverlustes nach der Tape-Stripping-Methode berechnet wurde.

Ergebnisse. Es wurde keine Korrelation ($r = -.18$, $p = .31$) zwischen chronischem Stress und SBR gefunden, wobei in einer linearen Regressionsanalyse nur 3,3 % der Variation in SBR aus chronischem Stress vorhersagbar waren. Die Hypothese, dass chronischer Stress einen Einfluss auf SBR hat, wurde abgelehnt. Zwei explorative Analysen, welche die mediierende Wirkung von Stimmung und die moderierende Rolle von gegenwärtigem Stress untersuchten, ergaben keine signifikanten Modelle. Die sekundäre Frage, die den Zusammenhang zwischen chronischem Stress und SBI untersuchte, ergab keine Korrelation ($r = .15$, $p = .39$), nur 2,4 % der Variation der SBI war auf chronischen Stress zurückzuführen. Chronischer Stress hat in der vorliegenden Stichprobe keinen signifikanten Einfluss auf die SBI.

Diskussion. Theoretische und methodische Erklärungen für die, vor dem Hintergrund der bekannten Literatur, unerwarteten Ergebnisse werden angeführt. Darüber hinaus werden Implikationen für die zukünftige Forschung und die Relevanz des Themas diskutiert.

Schlagworte: chronischer Stress, Regeneration der Hautbarriere, Integrität der Hautbarriere, transepidermaler Wasserverlust, Stimmung, Gesundheit

Chronic Stress and the Skin Barrier: the Role of Chronic Stress in the Recovery of the Stratum Corneum

Introduction: Problem Outline and Relevance of the Topic

The western society seems to have a stress 'epidemic', which is slowly reaching into every aspect of our everyday life (Jones et al., 2001). Almeida et. al (2020) found that stress in the daily lives of Americans increased significantly in the 2010s, compared to the 1990s. Stress did not only increase in its prevalence, but also in its severity and its potential to threaten future plans (Almeida et al., 2020). It's obvious that the COVID-19 pandemic represented an enormous stressful situation and was a possible cause of increased stress levels (Bartlett et al., 2020). To prevent the spread of the COVID-19 virus many countries all over the world imposed restrictions of personal movement and social contacts. The main focus was to minimize and battle the spread of the virus. Psychological wellbeing seemed less important and turned out to be one of the costs of fighting COVID-19 (Fiorillo & Gorwood, 2020).

It is important to know that stress has a major impact onto the human immune system and is a risk factor for numerous diseases (Segerstrom & Miller, 2004; Pinel, 2006). Since the skin as an organ is an active part of the immune system, it is affected by stress as well. Measuring the healing of the outer layer of the skin is one of many ways to examine the relationship between stress and the human body. Several studies investigated this relationship over the last decades (Altemus et al., 2006; Altemus et al., 2001; Garg et al., 2001; Muizzuddin et al., 2003; Robles, 2007). Only a few of those studies however examined the role of chronic stress in the healing of the skin. In the following study the relationship between chronic stress, conducted with a sub scale of the Trier Inventory for Chronic Stress (TICS; Schulz et al., 2004) and the skin barrier recovery will be examined.

Stress

One of the first researchers experimenting with stressful stimuli was the American physiologist Walter Bradford Cannon. He exposed cats to barking dogs and discovered biological changes in the function of the cats' sympathetic nervous systems (Cannon 1914, as cited in McCarty, 2016). Cannon reasoned, that when a creature was in fear, rage or pain this state of excitation was continued and enhanced by the secretion of a substance from the adrenal glands into the bloodstream. He assumed, that the effects of the released epinephrine speed up the recovery of fatigued muscles, liberate sugar into the bloodstream and drive the blood into the heart, lungs and limbs. In 1915 Cannon published a book about the bodily changes in pain,

hunger, fear and rage and came up with the term *fight- or flight response*. He emphasized, that neither the beginning nor the end of this mode can be voluntarily controlled, and therefore the subject has no influence on the biological changes, triggered by the release of adrenalin (Cannon, 1915, as cited in McCarty, 2016).

By increasing perceived stress in our lives, our interest in the phenomenon of stress is growing as well. Lazarus and Folkman (1984) assume that the growing prosperity of the western societies, which frees many people from concerns about survival and allows them to search for a higher meaning of life, might be one of the reasons of the increasing interest in stress research. Although the general interest in the phenomenon has grown enormously over the last decades, there is still some confusion on the definition of stress and how to conceptualize it. In the popular perception stress is seen as something, that needs to be cured or avoided (Jones et al., 2001). Selye (1976) came up with the term *eustress*, for the positive kind of stress, which makes one perform better and is often forgotten in literature about stress. According to Selye (1976) stress is not something to be avoided at all costs, it can be useful in activating instinctive behavioural responses. By his definition "Stress is the nonspecific response of the body to any demand made upon it" (Selye, 1976, p. 137). In the following chapter a more detailed view of definitions of stress will be given.

Stress theories

Over the past decades numerous researchers came up with their own attempts to define stress. The sheer number of definitions certainly has not helped to clarify the meaning of the term (Jones et al., 2001). Below I want to focus on two of the most popular theories: Selye's general adaption syndrome (GAS) and the transactional stress model by Lazarus and Folkman.

When Selye established the theory of the general adaption syndrome in 1956, he described two sides of the stress reaction (Selye, 1956, as cited in Wheaton, 1997). On one hand there are those adaptive changes in the organism, which enable a faster flight, mobilize energy for a fight or increase anti-inflammatory defence. On the other hand, long periods of stress cause severe bodily changes. In the theory of the GAS, there are three stages of coping with stressful events: the alarm reaction, the stage of resistance and the stage of exhaustion. In the first stage, stress hormones are released and blood pressure starts to rise. During the stage of resistance, the organism is still on guard, although to a lower extent than it was when the stressful event started. Eventually the body's defences grow weak and the production of stress hormones slows down. Finally, in the third stage of exhaustion, the body's adaptive energy is drained. It can no longer adapt to the stressful events, which leads to overall health issues. While Selye based his theory on physiological stressors only, it's evident by now that psychological

stressors have the same impact (Wheaton, 1997). Selye's model was one of the biggest influences on stress research (Jones et al., 2001; Wheaton, 1997).

Although Selye provided one of the most influential models in the history of stress research, he did not define the stressors themselves (Wheaton, 1997). According to Wheaton (1997) a stressor must be capable of threatening a persons' integrity, if they occur in their most extreme form.

Another conceptualization of stress was published by Lazarus and Folkman (1984). They define it as a transactional process between the person, the situation and the appraisal of the latter. In their theory they emphasize on three stages of this process: primary appraisal, secondary appraisal and coping. The primary appraisal is an assessment of the situation, which is then categorized as being either irrelevant, benign-positive or stressful. Stressful situations are then classified as a *threat*, a *challenge* or a *loss*. While a *loss* refers to harms that have already happened in the past, *threat* and *challenge* appraisals refer to anticipated harms that might be the outcome of the situation. Even though threat and challenge appraisals are negatively correlated, they are not two ends of a single continuum and can occur simultaneously (Skinner & Brewer, 2002). Within a challenge the person's focus lies on the personal growth that the situation could bring while threats are potential dangers to one's well-being. During the secondary appraisal the person assesses internal (e.g., health, self-esteem) and external (e.g., social support, social network) coping resources to answer the question if one is able to cope with the stressful situation. Distress will result if the situation is considered stressful and one perceives an inability to adequately cope with one's internal or external resources. According to Lazarus and Folkman (1984), there are two broad categories of coping mechanisms. Emotion-focused coping strategies are used by the person to regulate or reduce the distress, resulting from the situation. Problem-based coping aims to directly change the elements of the stressful situation (Lazarus & Folkman, 1984).

Acute and chronic stress

In 1984 Wheaton was just about to develop his curiosity about chronic stress when a bridge collapsed between New York and Boston (Wheaton, 1997). While the media and authorities were looking for the possible cause of the collapse, he felt like the search for an event that precipitated the collapse was misguided. He compares this hunt for a cause of the collapse to stress research, in which scientist often try to relate the stress as an outcome to a discrete event that acts as a cause. Later the inspectors found that the bridge collapsed due to long-term rusting. That led Wheaton to the conclusion that in the human psyche is no need of

a trauma or life event to trigger a collapse, but "long term rusting" by chronic stress can lead to a break down as well.

Schulz et al. (2004) provide a detailed description of the differences between acute and chronic stressors. According to them, acute stressors are defined by singular and unusual events with a sudden beginning, a relatively short duration and a clear ending. Further, acute stressors are often defined by unfamiliar situations. Chronic stressors however are defined by the absence of a distinct beginning or recur episodically. Usually, they endure a relatively long time and lack a foreseeable ending. Chronic stress can also be caused by so called *non-events*, meaning the absence of a desired event (e.g., child birth) (Wheaton, 1997). Acute stress can turn into chronic stress if one has insufficient coping skills (Schulz et al., 2004).

Another attempt to define stressors was made by Elliot and Eisdorfer (1982). Their taxonomy for the characterization of stressors primarily focuses on their duration and proposes four types of broad stressors: acute time limited stressors (e.g., mental arithmetic), stressful event sequences (e.g., loss of partner, which triggers a series of challenges), chronic intermittent stressors (e.g., conflict-filled visits to in-laws) and chronic stressors (e.g., being a refugee). Baum and colleagues (1993) found that there is a fifth type: the distant stressors, which are traumatic experiences from the past with long lasting impacts on a persons' psychological and physiological health. These categories can be sub summarized into the two main categories of acute and chronic stressors. Acute time limited stressors and stressful event sequences can be assigned to the former, while chronic intermittent stressors, chronic stressors and traumatic experiences constitute the broad category of chronic stressors.

Above all form of stress, particularly chronic psychological stress is strongly related to health issues of all kinds (Pinel, 2006). Researchers agree that the physical health heavily depends on the level of chronic stress (Becker et al., 2004; Hunter et al., 2015; Jones et al., 2001; Zorrilla et al., 2001). In the following a short overview of the pathways of stress onto the physical health will be given.

Stress and the body

Whenever the human body is exposed to threatening stimuli, no matter if they are physical (e.g., cold temperature) or psychological (e.g., death of a close person), it reacts with a series of physiological changes, called the stress reaction (Pinel, 2006). Most of these changes find their origin in the activation of the hypothalamus. Although the hypothalamus makes up less than 1% of the brain's total mass, its influence on physiology and behaviour is massive (Bear et al., 2007).

Hans Selye was the first who reasoned that the body's stress response was initiated by a hypothalamic activation of the pituitary gland. He emphasized the role of the anterior gland of the pituitary and the influence of the adrenocorticotropic hormone (ACTH) onto the adrenal cortex (Pinel, 2006). By now it is clear, that there is a second major pathway through which the hypothalamus triggers the body's stress response: the adrenal-medullary system.

Most modern, psychological stress theories agree on the co-existence of the mentioned physiological pathways of the stress reaction (Pinel, 2006). In the following, I want to provide a short summary of these systems.

The Hypothalamic-Pituitary-Adrenal (HPA) Axis

Even though the HPA Axis influences numerous physiological processes, it is best known for its role in our body's reaction to stress. When a person is exposed to stressful, threatening stimuli, the central nucleus of the amygdala gets activated by the neo cortex. The amygdala stimulates the release of corticotropin-releasing hormone (CRH) in the hypothalamus.

The pituitary consists of an anterior and a posterior lobe with fundamentally different functions. The magnocellular neurosecretory neurons of the hypothalamus extend axons downwards the stalk of the pituitary gland into the posterior lobe. While the posterior lobe is an actual part of the brain and receives information through magnocellular neurosecretory neurons from the hypothalamus, the anterior lobe of the pituitary is a gland (Bear et al., 2007). The parvocellular neurosecretory neurons of the hypothalamus communicate by releasing hormones like CRH into a network of blood vessels, called the hypothalamic pituitary portal circulation. CRH then binds to receptors of the anterior pituitary and causes it to release adrenocorticotropic hormone (ACTH). When ACTH reaches the adrenal cortex, it stimulates the release of cortisol into the blood. Once cortisol is released into the bloodstream, it supresses the immune system and mobilizes the body's energy reserves to face the negative situation or stimuli. Since cortisol is a lipophilic molecule, it can easily pass the blood-brain barrier and act on hypothalamic neurons to stop the CRH release like a negative feedback loop to maintain homeostasis. Neurons with cortisol receptors are found all over the brain, producing widespread changes in the both the body and the brain (Bear et al., 2007). Even though ACTH is an important hormone in the acute reaction to stressful stimuli, it can harm the body's immune system when it's released over a prolonged period of time (Pinel, 2006).

The adrenal-medullary system

It can take the HPA Axis several minutes from the activation of the amygdala until the significant rise of cortisol levels in the blood (Bear et al., 2007). The adrenal-medullary system is another, much faster, pathway of the stress response.

The hypothalamus controls the autonomic nervous system, which is a neuronal network responsible for internal body processes as blood pressure, body temperature and digestion. The signals sent through the spinal nerves and the nerves connected to them travel within nanoseconds from the hypothalamus downward to the adrenal medulla. Epinephrine and norepinephrine are then released from the adrenal glands into the bloodstream (Gerrig & Zimbardo, 2007). These two hormones activate the sympathetic and supress the parasympathetic division of the autonomous nervous system, causing a dilation of pupils, an increase of the heartrate and a suppression of digestive and reproductive functions, to name just a few consequences (Bear et al., 2007).

The Human Immune System

In the 1970s more and more reports emerged, showing that stress might reduce the body's resistance to infectious diseases (Pinel, 2006). Until then the causes of this diseases were seen to be of a mere physiological nature. The research field of psychoneuroimmunology has emerged from the increasing number of theories and data indicating strong interactions between psychological factors, the nervous system and the immune system.

To protect the body from infectious diseases the immune system provides two kinds of barriers: natural immunity, as it is found in mucous membranes, and specific immunity, which serves to protect the body from distinct microorganisms (Segerstrom & Miller, 2004). Cells of the natural immunity are all-purpose cells, able to protect the system from many different pathogens within a relatively short time. Natural killer cells are involved in the natural immunity barrier, they use toxic substances to attack virally infected cells. Another type of cells providing natural immunity are macrophage. The macrophage cells are phagocytic, which means they can ingest foreign microorganisms (Pinel, 2006).

The specific immunity is subdivided into the cell-mediated and the humoral immunity. Due to their specificity, processes of the specific immunity are much slower but very efficient, compared to the natural immunity (Segerstrom & Miller, 2004). Once a phagocyte absorbs an infectious microorganism, it presents the antigen of the organism at its surface to attract T-lymphocytes and starts the cell-mediated immunity. When one of the T-lymphocytes has the matching receptor to bind to the antigen, a proliferation of the T-lymphocyte is triggered, that will finally lead to the destruction of the infectious microorganisms. The humoral immunity

relies on antigens and is the base for numerous vaccinations. B-lymphocytes bind to the antigen and start proliferation while releasing antibodies into the intracellular fluid. The antibodies bind to the antigens of virus, preventing it to enter other cells. Further they can neutralize bacterial toxins and enhance natural immunity (Pinel, 2006; Segerstrom & Miller, 2004). T-helper cells are involved in both specific and humoral immunity, producing different cytokines in each. Those cytokines, in turn activate T-cytotoxic cells and natural killer cells within the cell-meditated immunity and activate B-lymphocytes to combat pathogens in the humoral immunity (Segerstrom & Miller, 2004).

Stress and the immune system

Segerstrom and Miller (2004) mention three possible pathways for the influence of stress on the body's immune system. The first is the connection of the brain and the lymphoid tissue through sympathetic fibres. When epinephrin or norepinephrine is transported through those fibres it will bind to adrenergic receptors, found in all of the mentioned lymphocytes (Ader et al., 1990). The HPA-Axis and the adrenal medullary system are summarized as the second pathway between stress and the immune response (Segerstrom & Miller, 2004). The released epinephrin, norepinephrine and cortisol from the adrenal gland and the adrenal medullary bind to receptors on white blood cells, regulating their distribution and function (Ader et al., 1990). The third pathway listed by Segerstrom and Miller (2004) refers to behavioural changes due to stress resulting in unhealthy activities (e.g., drinking alcohol) and finally leading to immunological consequences.

The global immunosuppression model, initiated by Selye's (1975, as cited in Segerstrom & Miller, 2004) finding of thymic involution, states that stressors lead to a broad immunosuppressive response. Although early studies supported the model for chronic stressors, it would not have been evolutionary adaptive for acute fight-or-flight stressors (Segerstrom & Miller, 2004). The biphasic model, proposed by Dhabhar and McEwen (1997) states that acute stress enhances the immune response, while chronic stress does the opposite.

To describe the relationship between stress and the immune system Segerstrom and Miller (2004) published a meta-analysis in which they gathered and analysed data of more than 300 empirical studies from the past four decades. They categorized stressors by their duration, using the classification of Elliot & Eisdorfer (1982), and examined each type separately. In general, the results of their meta-analysis proposed that stressful events reliably alter the immune system and that the characteristics of this immunological changes depend on the duration of these events. Further they were able to show that acute, time limited stressors induced an adaptive increase in natural immunity, while specific immunity was supressed. From

an evolutionary point of view these findings seem adaptive since the specific immune system affords much more time and energy than the natural immune system. When our ancestors were hurt from a bite or a scratch during a fight-or-flight situation they would benefit the most from an immune response that protects the body from a possible infection but still does not divert excess energy from the flight behaviour (Segerstrom & Miller, 2004).

In line with the findings of Dhabhar and McEwen (1997), Segerstrom and Miller (2004) found that chronic stressors were associated with reliable decreases in all functional immune measures. They reasoned chronic stressors might be perceived as less controllable and therefore have a severe impact on psychological and physiological health. In a meta-analysis on 82 studies Zorrilla et al. (2001) were able to support the findings of different immunological impacts of acute and chronic stressors. Kiecolt-Glaser et al. (2002) conclude that especially chronic psychological stress is connected to health impairments.

Stress and wound healing

The skin is more than just a physical barrier between our internal organs and the outer world. It's an important part of the human immune system and therefore it seems obvious, that it's affected by stress as well. It's the largest organ in the human body and its major functions are preventing the body from dehydration and protecting it from harmful environmental influences (Hänel et al., 2013). It continuously encounters diverse pathogenic microorganisms and defends the body by attacking them. Many different cells and their various interactions define the skin as an active organ of the immune system (Salmon et al., 1994). The epidermis, also known as skin barrier, is the outer layer of the skin and consists of five layers: the stratum basale, the stratum spinosum, the stratum granulosum, the stratum lucidum and the stratum corneum (SC) (Chiang & Verbov, 2020).

Wound healing involves several stages: clot formation, inflammation, proliferation and remodelling. The early stages of wound healing depend heavily on several proinflammatory cytokines, such as interleukin-1 alpha (IL-1α), interleukin-1 beta (IL-1β), interleukin-6 (IL-6) and tumour necrosis factor alpha (TNF-α). These cytokines attract phagocytes to the wound site, which are needed in the proliferative phase for remodelling the tissue (Gouin & Kiecolt-Glaser, 2011). To provide a functioning barrier, keratinocytes form the cornified envelope (CE) through a process called cornification. The CE surrounds cells in the SC. To ensure the correct formation of the CE, cytokines engage in highly complex cell communication processes, controlling the function and expression of many structural proteins, fatty acids and enzymes. Further, cytokines modulate the gene expression of keratinocytes and determine the quality of the skin barrier and its recovery from wounds (Hänel et al., 2013). There are three commonly

used experimental paradigms to investigate wound healing in the laboratory: punch biopsies, suction blisters and tape stripping.

Biological pathways of stress-altered wound healing

Since stress has various impacts onto the immune system, it's obvious that short term and chronic stressors have an influence on the skin and the processes of wound healing, as well. According to Gouin & Kiecolt-Glaser (2011), stress delays wound healing through multiple physiological pathways. One of these pathways is an enhanced production of glucocorticoids, adrenaline and norepinephrine following the activation of the HPA- and Adrenal-Medullary Axis. Studying wound healing of mice, Hübner et al. (1996) were able to show, that stress-induced glucocorticoid production decreases the cytokine production, leading to slower healing of the wound. The expression of several cytokines (IL-1α, IL-1β, & TNF-α) was decreased by the researchers' external admission of glucocorticoids. They state that the initial inflammatory phase of the wound is affected by stress through a neuroendocrine pathway. When Gallucci et al. (2000) studied wound healing of IL-6 deficient mice, they were able to show that their wounds took three times longer to heal, than wounds of normal mice. Gouin & Kiecolt-Glaser (2011) reason, that the healing process is a cascade and deficits of the earlier stages might have various consequences onto the later. With the suction blister method researchers are able to assess in vivo cytokine expression at the wound site while studying the healing process. Through the analysis of a salt solution, which is applied at the wound site, cytokine expression can be measured through the stages of healing (Gouin & Kiecolt-Glaser, 2011). Glaser and colleagues (1999) used the suction blister method to study the relationship between psychological stress and the cytokine expression at a wound site. The 36 women filled out two stress questionnaires before their wounding. The researchers found significantly lower levels of IL-1α levels at the wound site of women who reported more perceived stress. In 2003 Broadbent et al. analysed the wound fluid of patients after their inguinal hernia surgery. Those who reported greater preoperative self-perceived stress had significantly lower amounts of IL-1α in their wound fluid and their recovery was significantly slower.

Oxytocin and vasopressin, known for their role in social bonding and modulating the physiological stress response, seem to play a role in wound healing as well (Gouin & Kiecolt-Glaser, 2011). To study the relationship between oxytocin, vasopressin and wound healing 37 couples spent 24 hours in a hospital research unit. The researchers created small suction blister wounds on their forearms, made them participate in a social support task and took blood samples to monitor the subjects' oxytocin, vasopressin and cytokine levels. While those individuals with a higher oxytocin level showed more positive communication behaviour

during the social interaction task, their wound healing was also significantly faster compared to the people with a low oxytocin level. Individuals with higher vasopressin levels showed less negative communication behaviours and a greater production of TNF-α. The wounds of women in the upper vasopressin quartile healed the fastest (Gouin et al., 2010).

Catecholamines, as epinephrine and norepinephrine, constitute another pathway through which stress impairs wound healing. The mobility of keratinocytes, the cells located in the SC and known for being essential in wound healing, was reduced significantly when researchers injected norepinephrine into an in vitro sample of excised human skin (Sivamani et al., 2009). In the same study Sivamani and colleagues (2009) found faster healing of burn wounds of mice injected with an β-adrenergic receptor antagonist, compared to a group of control mice.

Furthermore, it should be mentioned that stress often leads to health-damaging behavioural changes. The use of alcohol and tobacco impact physiological healing processes (Gouin & Kiecolt-Glaser, 2011).

Tape stripping, skin barrier recovery and stress

Tape stripping provides a non-invasive method to measure the healing process of the skin barrier and therefore is widely used for research. Compared to punch biopsies or suction blisters, tape stripping is the least invasive approach to study the healing of the skin. It is the process of causing a minor injury to the SC by applying and removing several strips of cellophane tape (Walburn et al., 2009). The human body is constantly losing water through vaporization on the surface of the skin. After tape stripping the transepidermal water loss (TEWL) is increased at the wound site, compared to the uninjured skin. The recovery rate of the skin barrier can be assessed by repeated measures of the TEWL (Altemus et al., 2001).

Walburn et al. published an extensive review and meta-analysis about psychological stress and wound healing in 2009. To provide a systematic overview of what is known about the topic, they searched a range of databases for potentially relevant studies. After excluding irrelevant citations, non-empirical studies and studies focusing on the impact of complementary therapies or psychosis on wound healing only 22 studies (out of 2575 that were initially found), were included in the review. Five of the included studies used tape stripping to create a superficial wound. Only one of them did not show a significant negative impact of stress onto the skin barrier recovery. Below I want to give a short summary about the studies included in the meta-analysis and discuss their findings on the influence of different stressful stimuli and situations on the skin barrier recovery.

In 2001 Altemus et al. used tape stripping to investigate skin barrier recovery of women in 3 different conditions: psychologic interview stress, sleep deprivation and exercise. The

results showed that both the interview stress and the sleep deprivation caused a delay in the skin barrier recovery while the skin barrier of the third group, exercising on a treadmill 3 times a day, did not show any abnormalities. Additionally, they measured their participants' plasma levels of several hormones connected to the stress-response and cytokines and were able to show that the interview stress caused increases in the women's cortisol and norepinephrine levels and decreases in their cytokine responses.

Garg et al. (2001) examined the relationship between psychological stress and skin barrier recovery of 27 students. They took measures during periods of high stress (final examinations) and low stress (four weeks before and after final examinations). The students had significant slower skin barrier recovery in the examination periods, while perceived stress ratings increased.

Another study by Muizzuddin et al. (2003) investigated self-perceived stress, skin barrier strength and recovery of 28 women who were in the process of marital separation. The researcher defined barrier strength as the number of cellophane tapes required to disrupt the skin barrier. Compared to an age matched control group, the women undergoing a marital change in the form of a separation or divorce showed significantly slower skin barrier recovery. When skin barrier recovery was assessed 24 hours after tape stripping they found a strong correlation between self-perceived stress and the degree of recovery. There was no significant difference in skin barrier strength between the groups (Muizzuddin et al., 2003).

The only tape stripping study, included in the meta-analysis by Walburn et al. (2009), that showed an increase in skin barrier recovery by the experimental group was conducted by (Altemus et al., 2006). The researcher examined the skin barrier recovery of participants, diagnosed with post-traumatic stress disorder (PTSD). Altemus and colleagues found an enhanced skin barrier recovery for the participants with PTSD, compared to controls.

In a study conducted by Robles (2007), 85 participants were randomly assigned to one of three groups: *no stress*, *stress* and *stress with social support*. The Trier Social Stress Test (TSST; Kirschbaum et al., 1993) was used as stress-inducing manipulation, consisting of a 5-minute speech and a 5-minute arithmetic task. Participants in the *stress with social support* group had verbal support of a same-gender confederate while they prepared themselves for the TSST, while participants in the *no stress* group were instructed to read articles. Robles found that both *stress* conditions delayed the recovery of the skin barrier after tape stripping, compared to the *no stress* condition. Social support did not increase the speed of the skin barrier recovery (Robles, 2007).

In another study Robles and colleagues (2009) used tape stripping to investigate the stress-buffering role of trait positive affect (PA) on the skin barrier recovery. After the participants completed the self-report measure of PA, they were assigned to the same three tasks as in the study published by Robles in 2007. Participants with high PA in the stress tasks showed significantly faster skin barrier recovery than those who were in the stress tasks and reported low PA (Robles et al., 2009).

Skin barrier integrity

Another, scientifically often used, parameter of the skin is its integrity. Skin barrier function or stratum corneum integrity are other terms for the concept. While SBR describes the rate of wound healing after tape stripping through calculating at least 2 TEWL values assessed over time, skin barrier integrity (SBI) is assessed by the TEWL value of only one given time. SBI reflects the skins' permeability through the water loss on its surface and is often used in product development of the cosmetic industry.

In 2001, when Altemus and colleagues compared the SBR of women exposed to interview stress, sleep deprivation or physical exercise, they found a decrease in SBI of those in the interview stress condition. The researchers took measures of the basal TEWL of the participants forearm and face and were able to show that the facial SBI was significantly reduced in the mentioned condition (Altemus et al. 2001).

Choi et al. (2005) studied the influence of insomniac psychological stress on the SBI of mice. They showed that insomniac psychological stress altered the SBI and led its decrease.

Another study by Choe et al. (2018) aimed to examine the effects of acute psychological stress onto the SBI. The cortisol levels of the participants' oral mucosa were assessed to measure the stress level. A significant negative correlation was found between the cortisol level and the SBI. Further, a selective serotonin reuptake inhibitor was given to the participants, to relieve their stress. Decreased cortisol levels and increased SBI were found after the treatment with the selective serotonin reuptake inhibitor (Choe et al., 2018).

Other Factors influencing the Skin Barrier Recovery

While stress seems to play an important role on the SBR, there are several findings of other determinants of the skin barrier recovery as well. Below a short overview, of possible factors influencing wound healing, will be given.

Climatic conditions, such as humidity and temperature are two major physical influences on the healing of skin. Especially low humidity and cold temperature negatively affect skin barrier functions (Engebretsen et al., 2016). Chronological aging is another important factor, determining skin barrier functions. Aged skin has a reduced stratum corneum

hydration and elevated skin surface pH and is therefore susceptible to impaired healing and several dermatological diseases (Zhen et al., 2020).

Habits and lifestyle choices, like the consumption alcohol and cigarettes or the use of cosmetics are having a big impact on the skin barrier as well. Xin et al. (2016) conducted a case control study to compare the skin barrier recovery of smokers and nonsmokers. They were able to show that skin barrier recovery correlated strongly with the extent of cigarette consumption. Smoking appears to be negatively impacting skin barrier recovery.

Interpersonal behaviour plays a role in skin barrier recovery as well. In 2017 Robinson et al. published a study about the role of social interaction in wound healing after tape stripping. Participants were either assigned to a social closeness condition, where they engaged in a relationship building task and later had tape stripping together, while the control condition had no social support. The participants in the social closeness condition had significantly faster SBR and reported less self-perceived stress than the control group (Robinson et al., 2017).

Since psychological stress delays SBR, it's no surprise that interventions, emotional states and personality traits, which reduce stress, have a positive impact on the recovery of the skin barrier. Cole-King and Harding (2001) found a significant correlation between wound healing and anxiety and depression scores. Steptoe et al. (2005) were able to show that, positive affect was inversely correlated to the cortisol levels of their sample. Elevated cortisol levels are a precursor to several pathological conditions as diabetes and autoimmune diseases (Steptoe et al., 2005) and also play a role in cytokine expression and SBR (Altemus et al., 2001). According to Tugade & Fredrickson (2004), resilient individuals use positive emotions to reduce their psychological stress and improve their mood. Therefore, resilience and positive affect seems to have a moderating role in the relation between stress and SBR. As explained earlier, Robles et al. (2009) was investigating the stress-buffering role of trait positive affect on SBR. The researchers assigned the participants either to a stress or a no stress condition and assessed their positive and negative affect before tape stripping. The results showed that trait positive affect is positively correlated to faster healing of the skin.

Purpose of the Study

To summarise, it can be said that both psychological stress in various areas of life and interest in this phenomenon have steadily increased in recent decades (Jones et al., 2001; Lazarus & Folkman, 1984). While there is still some confusion on the definition of stress (Jones et al., 2001), by now it is evident, that stress, especially when it's chronic, has a major impact onto physical health and is connected to the overall functioning of the body's immune system (Dhabhar & McEwen, 1997; Segerstrom & Miller, 2004) and to the pathogenesis of several

diseases ((Pinel, 2006)). If the stress lasts long enough, the body can no longer adapt, leading to the possible serious health issues (Selye, 1976). Physiological, as well as psychological stressors can lead to those problems when they endure long enough (Wheaton, 1997). In other words: long term psychological processes lead to bodily changes.

As mentioned earlier, there are diverse pathways for the impact of stress on the body and the immune system (Segerstrom & Miller, 2004). The skin is only one organ out of many to reflect the bodily changes under stressful situations. Researchers use several methods to study the healing of the skin as a function of various variables. By modulating the gene expression of keratinocytes, cytokines are playing an important role in the skin barrier recovery from wounds (Hänel et al., 2013). Stress delays wound healing through multiple physiological pathways (Gouin & Kiecolt-Glaser, 2011) and it seems that especially cytokines are prone to a decrease in their production, triggered by stress (Glaser et al., 1999; Hübner et al., 1996). Research suggests that acute and chronic stress have different immunological impacts. Acute stress can enhance the immune response, while chronic stress seems to supress immunological mechanisms (Dhabar & McEwen, 1997; Segerstrom & Miller, 2004; Zorilla et al., 2001).

Several studies, using the tape stripping method to investigate skin barrier recovery as a function of other variables, showed that skin barrier recovery is delayed by stress (Altemus et al., 2001; Garg et al., 2001; Muizzuddin et al., 2003; Robles, 2007; Robles et al., 2009). None of these studies examined the role of chronic stress on the skin barrier recovery. Therefore, I want to investigate the effects of chronic stress on SBR. Inspired by the findings of Robles et al. (2009) about the role of positive affect in increasing the recovery rate of the skin barrier, and the outcomes in the analysis of Cole-King and Harding (2001), proving anxiety being correlated with delayed wound healing, an explorative analysis about a possible mediating effect of the present mood on the effect of chronic stress on SBR will be performed. Another exploratory sub question of the first research question will examine a possible moderating effect of baseline subjective stress on the effect of chronic stress on SBR.

The relationship between skin barrier integrity and chronic stress will be addressed as secondary question. Since previous research has shown that SBI is negatively affected by interview stress (Altemus et al., 2001), insomniac psychological stress (Choi et al., 2005) and acute stress (Choe et al., 2018), I want to investigate the effect of chronic stress on the SBI.

Research Questions and Hypotheses

The following questions for the present study arise from the theoretical background and the objective of the study:

1. How does chronic stress influence the regeneration of the stratum corneum?

H(1.1) Chronic stress delays the regeneration of the stratum corneum.

H(1.0) Chronic stress does not delay the regeneration of the stratum corneum.

1a. Does present mood mediates the effect of chronic stress on the recovery of the stratum corneum?

H(1a.1) Present mood mediates the effect of chronic stress on the recovery of the stratum corneum.

H(1a.0) There is no mediation effect of chronic stress on the recovery on the stratum corneum through the present mood.

1b. Does perceived stress moderate the effect of chronic stress on the recovery of the stratum corneum?

H(1b.1) Perceived stress increases the effect of chronic stress on the recovery of the stratum corneum.

H(1b.0) Perceived stress does not increase the relationship between chronic stress and the recovery of the stratum corneum.

2. Does chronic stress influence the skin barrier integrity?

H(2.1) Persons with high chronic stress show lower skin barrier integrity compared to persons with low chronic stress.

H(2.0) Persons with high chronic stress do not show lower skin barrier integrity compared to persons with low chronic stress.

Methods

To answer the hypotheses of the present study, data was collected within a research project of the "Music and Health Lab" of the university of Vienna's department for clinical and health psychology. Therefore, the contents of this thesis may incidentally show overlap (in terms of e.g. appendices) with theses by other students co-supervised by Dr. Jasminka Majdandžić. The project was conducted by Dr. Jasminka Majdandžić and Univ. Prof. Dr. Urs Nater to study the effects of music on the recovery of the skin barrier and to determine whether this effect is mediated by stress. Two studies were embedded in the project. The first study was titled "effects of music listening on psychological stress and skin barrier recovery". The title of the second study, which had a very similar method, with the difference of adding an acute stress intervention, was "effects of music listening after an acute stressor on psychological, cardiovascular and endocrine stress measures and skin barrier recovery". The TSST served as stress inducing procedure in the latter. Due to the possible confounding influence of the TSST onto other stress measures and the lack of comparability of the SBR of participants taking part in the TSST with participants that don't, in this work only data from the first study will be used. "Effects of music listening on psychological stress and skin barrier recovery" was a quantitative longitudinal experimental study. The study's main independent variable was the listening condition. The participants either listened to music, to an audio book or stayed in silence for 30 minutes. The main dependent variables were salivary α-amylase and cortisol, electrodermal activity, heart rate, and the skin barrier recovery.

Sample

All participants had to be female, since sex is known to have an impact on endocrine responses to stress (Allen et al., 1993). Participants had to be fluent in German language. Being a non-smoker was essential for partaking in the study. The Body Mass Index had to be in the normal range (18-25). Since stress hormone levels were assessed through their saliva for other researchers hypothesises, it was a prerequisite to have a regular menstrual cycle and to not use any hormonal contraceptives. Being pregnant or breastfeeding were further reasons for exclusions. The participants had to be healthy at the day of the examinations and it was made sure that they have no chronic somatic illnesses or specific allergies to patches or latex gloves. The use of drugs within the last 14 days and excessive alcohol use were exclusion criteria. Because the current research questions were embedded in a research project about the influence of music onto skin barrier recovery and stress it was important that the participants had neither hearing impairments nor absolute hearing. Participants with a music related profession or a

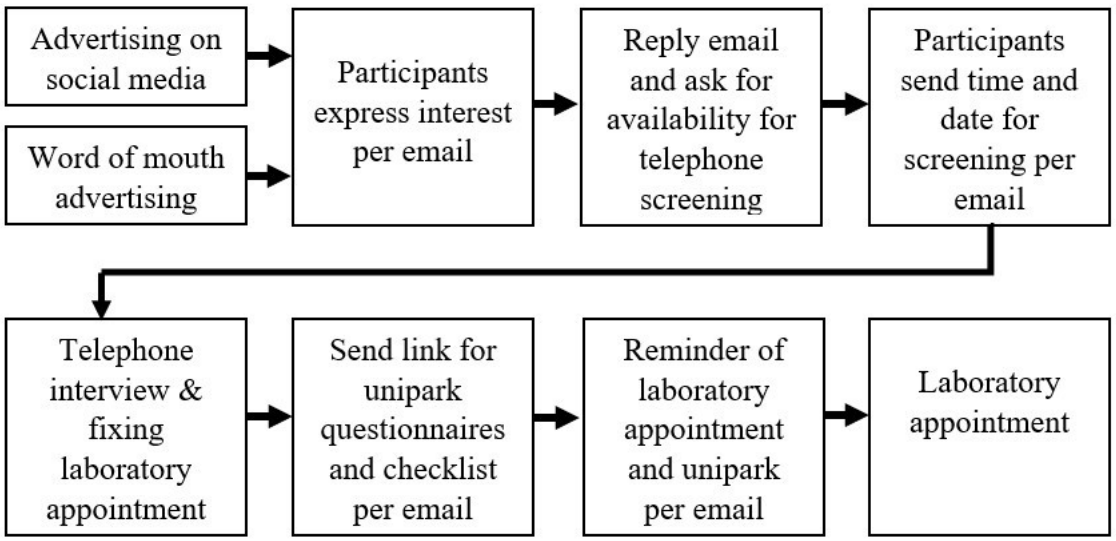
music related education were excluded as well. To ensure a safe tape stripping process several inclusion criteria had to be met by the participants: no chronic or acute inflammatory skin diseases, no allergies to adhesive tape, no rashes or burn marks on the left volar forearm and no intake of immunosuppressive drugs. For a full listing of the inclusion criteria see Appendix A.

Sampling Procedure

Participants were recruited through advertising on social media, by using a database of potentially interested persons for psychological experiments and by word of mouth. Participants, which completed the whole experimental procedure, were refunded € 35. When potential participants expressed their interest of taking part in the study a telephone interview screening was arranged. If participants met the requirements for the participation, they received an invitation for the testing at the university. To minimize the effects of the hormonal changes during the menstrual cycle all participants were tested in their early follicle phases. The date of testing therefore was calculated depending on the participants' menstrual cycle. Figure 1 depicts a more detailed view of the recruiting process.

Figure 1

Process of recruitment



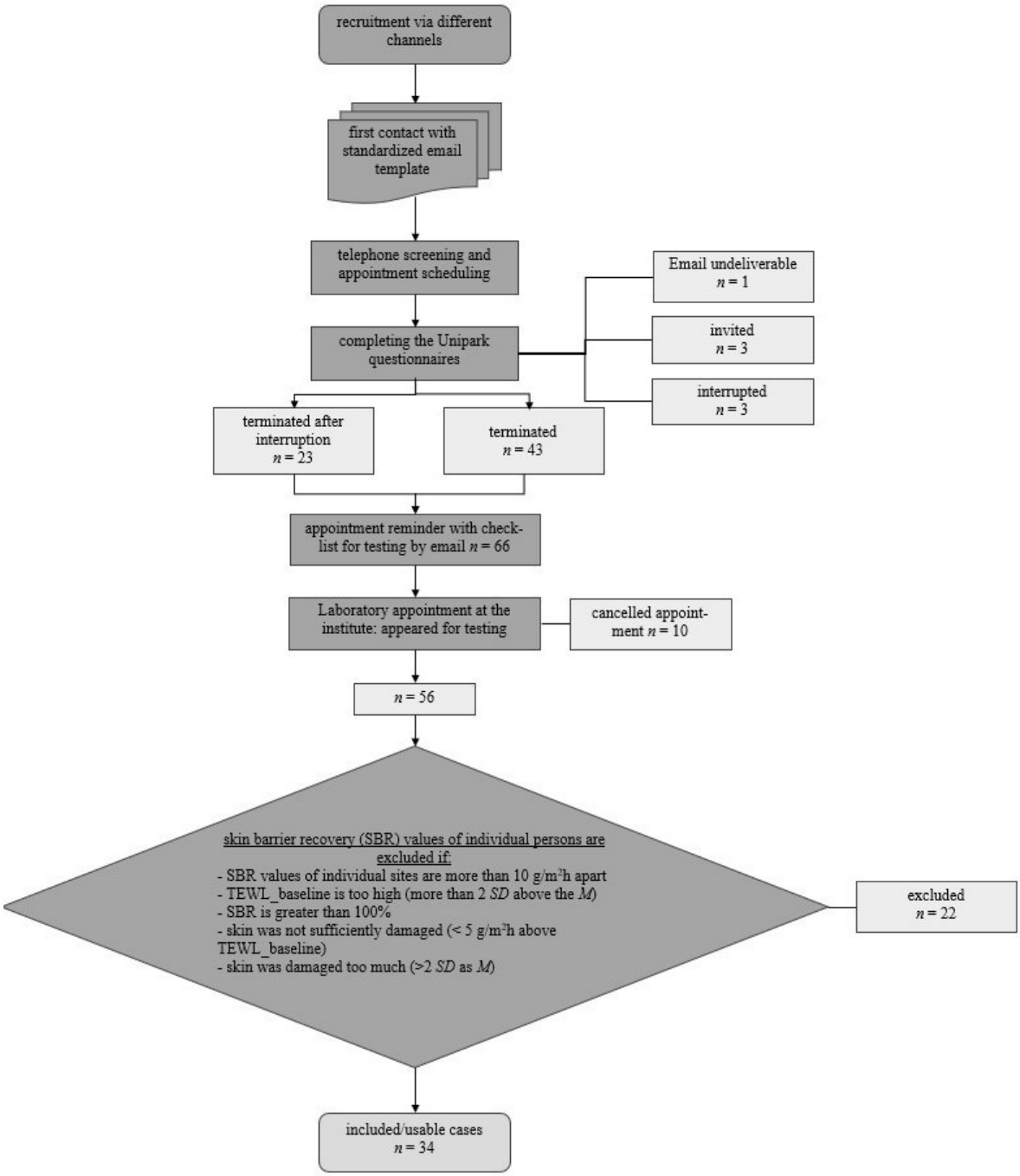
Response statistics

After the first contact via email 73 participants were screened and fulfilled the mentioned inclusion criteria in the course of the telephone interview. All of them received the invitation link for questionnaires embedded in the Unipark platform. Seven did not complete

those questionnaires and were excluded from the study (see Figure 2 for a more detailed view). The remaining 66 participants received an invitation for the laboratory appointment. Due to diverse, mostly personal reasons, 10 participants did not show up at the planned date. Out of the remaining 56 participants the TEWL data of 22 participants had to be excluded (a detailed discussion about the reasons for exclusion will be given later). The data of 34 participants was used for further statistical analysis.

Figure 2

Flowchart of the recruitment process with sample numbers

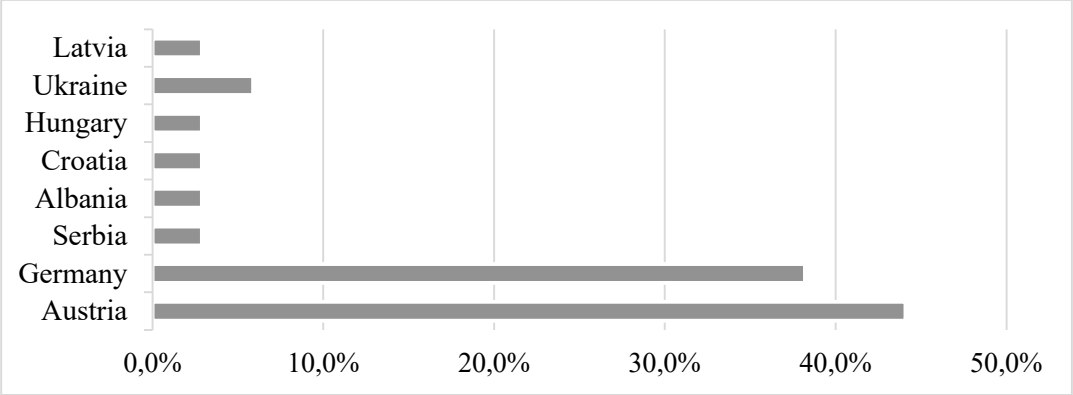


Description of the research sample

The final sample consisted of 34 female participants. The relatively small number of participants is partially due to the COVID-19 pandemic. During the several lockdowns, testing was impossible and even the times between the lockdowns it was hard to test participants because of the high infection risks during the laboratory session. Especially the saliva sampling and the long duration of each session increased the risk of spreading the virus. Further reasons for the relatively small size of the final sample are the long list of inclusion criteria and the error-prone TEWL measuring procedure. Participants had to be between 18 and 35 years old. The mean age was 23.9 years (SD = 3.5; min = 19; max = 35). Most of the participants were Austrians (48.6%) or Germans (34.3%), see Figure 3 for further information.

Figure 3

Nationalities of the sample

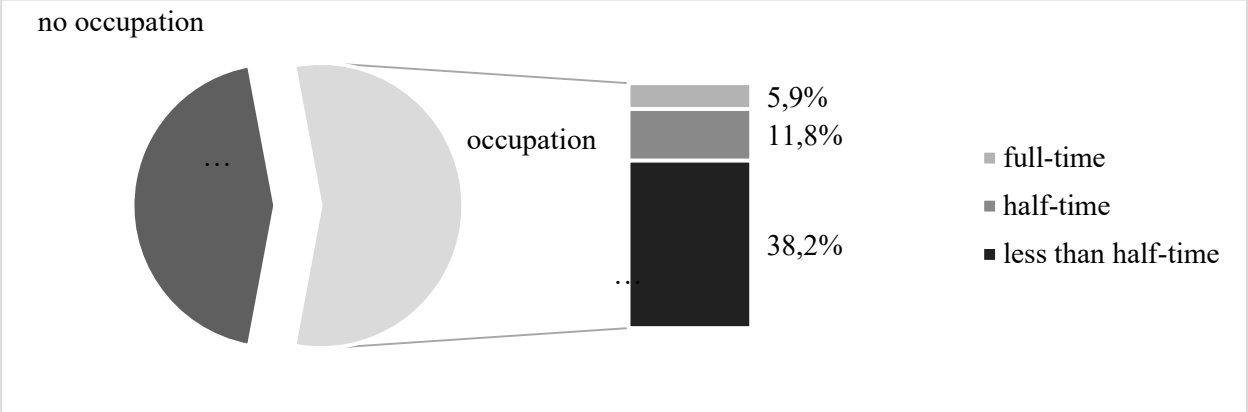


Note. n = 34.

The Body Mass Index of all participants was in the normal range between 18 and 25 with a mean value of 20.9 (SD = 1.46; min = 18; max = 24). The majority (44.1%) of the participants were living in a shared apartment. 20.6% of the participants were living alone or with their partner respectively, while 14,7% were living with their parents. 44.1% of the sample were in a partnership, while the others stated that they were currently single (55.9%). A majority of the participants had university training (82.4%). 2.9% had vocational training or training in a technical college respectively and 11.8% stated that they had no job training at all. 61.8% of the sample were working at least part time, for a more detailed view of the employment situation see Figure 4 below.

Figure 4

Occupation of the sample



Note. Out of the participants with no occupation (44.1%), 41.2% were in training while 2.9% were unemployed; $n = 34$.

Study Design

The present research project is a quantitative study. The main independent variable was the subjective rating of chronic stress, assessed by the Screening Scale for Chronic Stress (SSCS, Schulz et al., 2004) of the Trier Inventory for Chronic Stress (TICS, Schulz et al., 2004). The main dependent variable was the skin barrier recovery (SBR), calculated from measures of the transepidermal water loss (TEWL). Hypotheses are tested on the basis of the data and relationships between variables are identified and evaluated. The collection of data started on December 10, 2019 and data collected until November 20, 2023 was included in the analysis.

Materials

All questionnaires used are suitable for the target group.

Trier Inventory for chronic stress

The Screening Scale for Chronic Stress (SSCS) of the Trier Inventory for Chronic Stress (TICS; Schulz et al., 2004) was used to assess the participants' degree of self-perceived chronic stress. The TICS is a standardized inventory for the diagnosis of chronic stress and refers to the participants' subjective perception of stress in last three months. Ditzen & Nater (2006) state, the authors based the formulation of the items on the theoretical foundations of the transactional stress model by Lazarus & Folkman (1984). As stated above, subjective stress heavily depends on appraisal of the situation and one's resources. Therefore, the items of the TICS are formulated in a way that stress is already implied (e.g. "Although I try, I do not fulfil my duties as I should", Ditzen & Nater, 2006). The participants rate each item on a five-point Likert scale,

indicating how often they experienced a specific situation with the last three months (0 = never, 1 = rarely, 2 = sometimes, 3 = often, 4 = very often). Initially Schulz et al. (2004) suggested a two-factor model with the higher-order factors *high demands* and *lack of satisfaction*. The authors describe the *high demands* factor as "stress resulting from high demands in combination with job conditions and social conditions", while *lack of satisfaction* refers to the "lack of satisfaction of one's needs because of unsatisfactory job conditions and unsatisfactory social conditions" (Schulz et al., 2004, p. 38). According to a factor analysis by Petrowski et al. (2012) a nine-factor model provides the best model fit. Heuristically they can be grouped by the mentioned two higher-order factors (Petrowski et al., 2012).

The TICS consists of 57 items, constituting 9 scales of different aspects of chronic stress: social overload, lack of social recognition, social tensions, social isolation, pressure to perform, work overload, excessive demands from work and chronic worrying. Schulz et al. (2004) prove the inventory's reliability to be very good (Cronbach's alpha $\alpha = .91$, Rasch Reliability .83). Schulz et al. (2004) do not recommend using the sum score of the single scales but suggest using the score of the SCSS to measure chronic stress. The SSCS is composed of 12 items with five-point Likert scales. Participants rate how often they felt like "I was afraid to not be able to fulfil a task" or "my worries were overwhelming" within the last 3 months (Schulz et al., 2004). A sum score was calculated over all items of the SSCS, higher sums stand for more chronic stress.

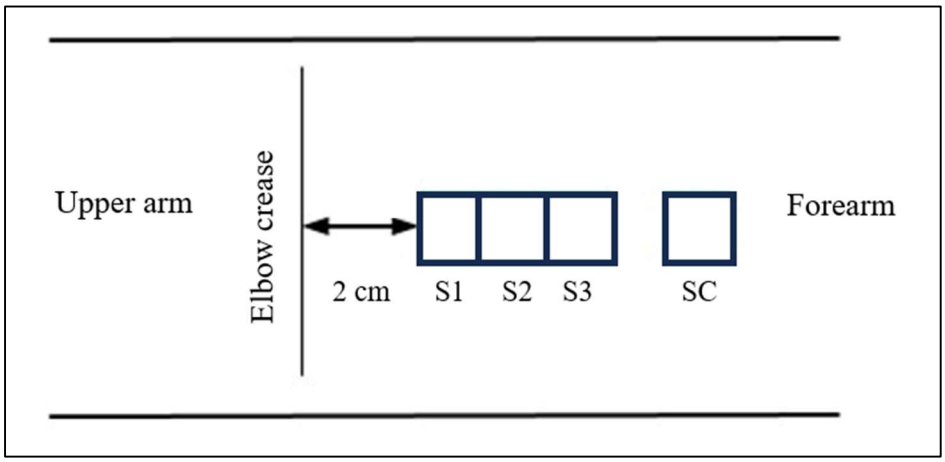
Schulz et. al (2004) provide norm tables for three different age ranges to assign t-transformed values to the SSCS sum scores. Those t-transformed values were used for further analysis.

Skin barrier recovery & skin barrier integrity

The SBR was calculated by using several measurements of the transepidermal water loss (TEWL). TEWL was assessed with a Tewameter (Tewameter® TM 300) manufactured by Courage Khazaka (www.courage-khazaka.de). TEWL was measured on four sites of the inner, forearms on the participant's non-dominant arm. In Figure 5 the arrangement of the test sites (S1, S2 & S3) and the control site (SC) is shown.

Figure 5

Arrangement of the TEWL test sites



Prior to every test session 3x40 strips of adhesive tape were prepared. The probe of the Tewameter was put into a probe heater to reach a temperature of 34°C (skin temperature). The room temperature was kept constant (22.5-23.5°C) by heating or air conditioning and humidity was between 40-60%.

Before tape stripping, the participants inner lower arm was shaved and the test and control sites were marked with a stamp. The sites had to stay uncovered and untouched for the rest of the test session. After marking the sites, the baseline TEWL of each site was measured. The baseline values were then used to judge whether the impairment of the skin by tape stripping is sufficient. After using 20 strips of tape the researchers measured the TEWL values of the test sites to check if the skin was sufficiently impairment at each site (difference of 15 $g/h/m^2$ to $TEWL_{baseline}$). If that was not the case, another 10 strips were used at each site, followed by another measurement of the impairment. A maximum of 40 strips was used on each site. While measuring, the probe was held on the skin until 20 consecutive measurements with a $SD < 0.5$ were reached. If the *SD* was too big, measuring was stopped after 90 seconds. The researcher noted the TEWL values, *SD* and the times for each site on a TEWL data sheet. The room temperature and humidity were noted as well.

The skin barrier recovery (SBR) for each site and time was calculated by putting the difference between the TEWL value shortly after the tape stripping ($TEWL_{impaired}$) and the TEWL value of the respective time ($TEWL_{time}$) in relation to the maximum impairment, calculated using the difference between $TEWL_{impaired}$ and the TEWL value measured as baseline prior to the tape stripping ($TEWL_{baseline}$). The following formula was used to calculate the SBR for each site and time:

$$SBR_{Site} = (TEWL_{impaired} - TEWL_{time}) / (TEWL_{impaired} - TEWL_{baseline}) \times 100$$

The SBR is stated as a percentage, the higher it is, the more the skin has healed back to its original condition. Individual participants were excluded if the $TEWL_{baseline}$ was too high (more than 2*SD* above the mean) and in case the skin barrier recovery was more than 100%. Furthermore, participants were excluded if the skin was not sufficiently impaired (impairment was less than 5g/m^2h above baseline) or if it was too damaged (more than *2SD* above the mean). All three sites were averaged if they were within a range of 10 g/m^2h. Otherwise the closest two sites (if they differed less than 10 units from each other) were used to calculate a mean, which served as value for the third site.

TEWL measurements were taken prior ($TEWL_{basline}$) and post ($TEWL_{impaired}$) to tape stripping as well as 55 minutes ($TEWL_1$), 85 minutes ($TEWL_2$), 115 minutes ($TEWL_3$) and 145 minutes ($TEWL_4$) after tape stripping. The skin barrier recovery is known to be the most distinct during the first 1.5 hours after tape stripping (Robles et al., 2009). See Figure 8 for a in depth view of the healing process. Therefore, the SBR value 85 minutes after the disruption of the skin was used for the testing of the main hypothesis. The skin barrier integrity was assessed with the $TEWL_{baseline}$ measurements.

TEWL Data of 56 participants was collected. The skin of 15 participants was not sufficiently impaired (<5 gm^2/h above baseline) and therefore dismissed from further analysis. The TEWL values of three participants increased with respect to $TEWL_{impaired}$, their data was excluded as well. Two participants showed a SBR of more than 100%, the TEWL values of one participant were too wide apart to calculate a mean and one participant was excluded because the impairment of the skin was too big. The data of the remaining 34 participants was used for answering the research questions.

The skin barrier integrity of the participants was assessed with the $TEWL_{baseline}$ value. A lower $TEWL_{baseline}$ value stands for a higher skin barrier integrity.

Baseline subjective stress

To assess the subjective rating of current stress of the participants a visual analogue scale (VAS) was used. The VAS was 100 mm long and the participants used a pen to chart their present stress level. The distance between the start of the VAS and the indicated stress level was then measured to determine the participants' baseline subjective stress just before tape stripping. A higher mark on the VAS stands for more baseline subjective stress of the participant.

Present mood

The Multidimensional Mood Questionnaire (MDBF; Steyer et al., 1997) was used to assess the present mood of the participants. The MDBF consists of 3 scales: good mood-bad mood, alertness-tiredness and calmness-nervousness. The score of the good mood-bad mood scale was used as the variable present mood.

The short form of the questionnaire was used, which consists out of 12 items. Participants rated items like “Right now, I feel good” on a five-point Likert scale. The internal consistency of the MDBF was proven to be good with a Cronbach’s alpha between .73 and .89.

Reliability analysis

Because of close-ended format of the used questionnaires (TICS, VAS, MDBF) the objectivity in the sense of security against miscalculations and unambiguity of interpretation was given. To provide reliability in the sense of the internal consistency of the used psychometric procedures the item-to-scale reliabilities were calculated. The basis for this calculation was the response behaviour of the 34 included participants (Moosbrugger & Kelava, 2012).

To judge the item-to-scale reliabilities the Cronbach alpha coefficient was used. Every item is treated like an individual part of a test. Further the corrected discriminatory power was used to judge the reliability of the respective scales (Moosbrugger & Kelava, 2012; Rost, 2004). Table 1 shows the resulting coefficients for the internal consistencies of the scales.

Table 1

Coefficients for the internal consistency of the SSCS

	Number of items (*k*)	Cronbach (α)	corr. discrim. power (r_{it})	Data sets (*n*)
SSCS	12	.91	.47-.78	34

The results of the reliability analysis delivered a high value of Cronbach alpha of α = .91 for the measurement accuracy and reliability of the SSCS. Therefore it was possible to summarize the item scores to a sum score for the scale. The corrected discriminatory power of the items was good too.

Research Procedure

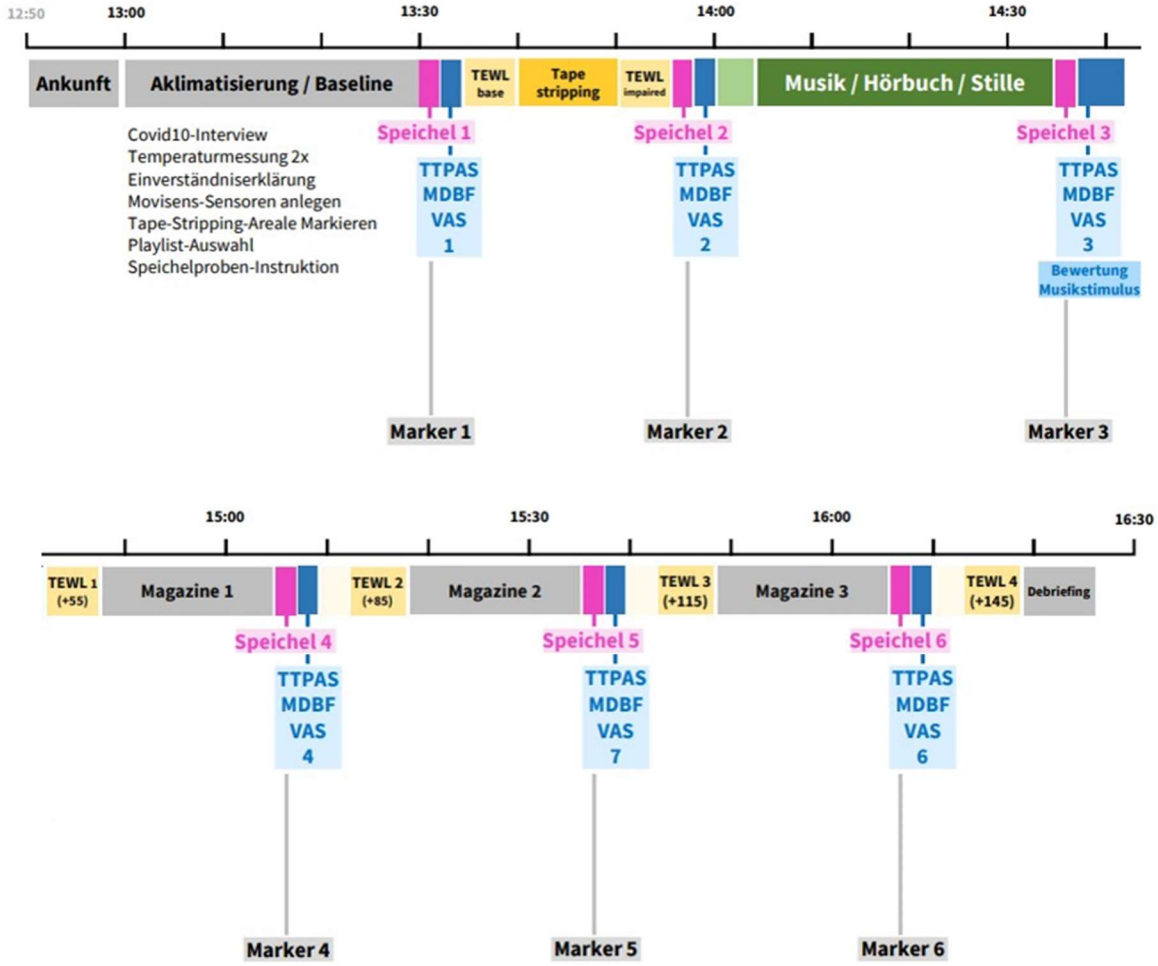
Before taking part in the actual experiment at the department for clinical and health psychology, participants filled out several questionnaires online embedded in the Unipark platform (ww3.unipark.de). Participants were reminded per email to complete the online survey and received a checklist informing them about important tasks prior to the testing. They were asked to refrain from exhausting physical activity two days prior to the experiment. Further they were informed to not drink any alcohol or caffeine and to not use any lotions, oils or moisturizers on their arms 24 hours before the laboratory appointment. In the following a short summary of the online questionnaires and the assessed variables will be given, all of them were presented in German language.

The Prime MD Patient Health Questionnaire (PHQ-D; Löwe et al., 2002) was used to screen for common mental disorders such as anxiety, eating disorders and depression. An additional screening for depressive disorders was provided by the Becks Depression Inventory (BDI; Beck et al., 1996). The TICS (Schulz et al., 2004) was used to assess the participants chronic stress within the last three months. Another questionnaire, measuring the self-perceived stress of the last month, was the 10-item Perceived Stress Scale (PSS-10; Cohen et al., 1983). The characteristics of the participants' personality traits neuroticism, extraversion and openness to experience were measured with the respective subscales of the NEO-Five-Factor-Inventory (NEO-FFI; Costa & McCrae, 1992). Possible symptoms of the premenstrual syndrome were assessed with the Premenstrual Symptoms Questionnaire (Takeda et al., 2020). The musical preferences were measured with the Music Preference Questionnaire (MPQ-R; Nater et al., 2005) and the cognitive style of music listening was assessed with the Music-Empathizing-Music-Systemizing Inventory (MEMS; Kreutz et al., 2008). Furthermore, participants completed the Brief Music in Mood Regulation Scale (B-MMR; Saarikallio, 2012). The participants' openness to absorbing and self-altering experiences was assessed with the Tellegen Absorption Scale (TABS; Tellegen & Atkinson, 1974).

The start of each laboratory appointment was set at 12:50 p.m. (see Figure 6). The first 10 minutes were used to welcome the participant and lead her to the room, where the experiment took place. Since most data was collected during the COVID-19 pandemic several tasks were included in the procedure to make the experiment as safe as possible for the participants and the researchers. At every laboratory session the participant and the whole research team completed a COVID-19 survey and the forehead temperature of each person was measured twice, using a contactless clinical infrared-thermometer.

Figure 6

Process of the laboratory session



Participants were informed about the tasks of the experiment and filled out a consent form. The participants were instructed about giving saliva samples and one test sample was given. After determining their handedness, participants were asked to pull up the sleeve of their non-dominant arm and the sensor to measure the electrodermal activity (EDA) was mounted on their non-dominant hand. The researcher instructed the participant on how to set a marker in the EDA data file through tapping twice onto the EDA sensor. To provide electrocardiographic monitoring a sensor belt was fixed around their chest. As a next step the sites for the tape stripping method were marked with a stamp and participants were told to not touch or cover the sites for the remainder of the session. The participants of the music condition then had to choose their favourite playlist out of five, while the participants assigned to the audio book condition chose between five topics of audio books. The volume of the chosen music playlist or audiobook was set and the respective choice was noted.

At exactly 13:25 p.m. the participant was told to tap onto the movisens wristband and start gathering her saliva for the next 2 minutes while filling out three questionnaires. They rated their mood, tiredness and nervousness on the five-point Likert scales of the Multidimensional Mood Questionnaire (MDBF; Steyer et al., 1997). The Types of Positive Affect Scale (TTPAS; Gilbert et al., 2008) was used to measure the degree to which the participants experience different positive emotions. Additionally, the participants rated their self-perceived stress level on a VAS. When the first saliva sample was collected and the surveys completed, one of the researchers took the baseline TEWL measurements to determine the skin barrier integrity. After that, the tape stripping was executed. A detailed description of the tape stripping procedure is given later. By measuring the $TEWL_{impaired}$ after tape stripping, the researchers made sure that the impairment of the skin was sufficient. As a next step, another saliva sample was collected, participants set the second marker on the movisens wristband and answered the TTPAS, MDBF and VAS a second time. In the next 30 minutes the participants of the music and audiobook conditions listened to the music playlist or audiobook of their choice. The participants who were randomly assigned to the silence condition, had to wear headphones as well to suppress ambient noise. They were asked to lie onto a lounger and to get into a comfortable position. The researcher offered a blanket to the participant. The headphones and the blanket were adjusted by the researcher to minimize the chance of the participant touching the TEWL-measuring site. Before leaving the room, the researcher made sure that the participant was in a comfortable position and instructed her to avoid moving during the next 30 minutes. Finally, the playlist or audiobook was played, the light was turned off and the researcher left.

After 30 minutes the researcher silently entered the room, carefully told the participant that the lights were about to be turned on again and asked her about her well-being. After that, the third saliva sample was collected. The participants again had to fill out the TTPAS, MBDF, VAS and an additional survey to rate the music, audiobook, or silence. Another TEWL measurement was made, and the participant was instructed about the further tasks. Separated by 30-minute pauses, in which they were offered several magazines to read, the participants had to do three more sessions of giving saliva samples, answering the mentioned surveys and TEWL measurements. In the sixth and last survey session, the participants additionally answered the German version of the Barcelona Music Reward Questionnaire (Mas-Herrero et al., 2013).

At the end of the session the movisens sensors were removed, the participant received a debriefing and had the opportunity to ask questions about the procedure and the aims of the study. Information about the monetary compensation was given.

Statistical Analysis

IBM SPSS® Statistics 29 for Windows® was used for the analysis for descriptive and inferential statistics. The level of significance was defined in accord with the probability of error as $\alpha = .05$. Therefore, results with $p \leq .05$ were defined as significant and results with $p \leq .01$ as highly significant while testing the hypotheses.

The effect sizes defined by Cohen's classification were used to interpret the results of the analysis. Cohen defined d values ≥ 0.20 as small, ≥ 0.50 as medium, while values ≥ 0.80 are referred to as large (Cohen, 1988).

Analogous to the effect sizes, the correlation coefficient r was rated according to Cohen's recommendations. Ranges of $r \geq .10$ were interpreted as weak, $\geq .30$ as moderate and $\geq .50$ as strong (Cohen, 1988).

The confidence intervals show the range of values around a statistical result which contains the true value to a specified likelihood. In the present analysis 95 confidence intervals were calculated with lower and upper limits (95%-CI [lower; upper limit]) were used (Field, 2018). The usual prerequisite tests for the application of parametric methods were carried out in accordance with the central theoretical requirements.

Inferential statistics and precondition tests

The hypotheses for research questions 1 and 2 were investigated with correlation analysis and regression analysis. A scatterplot chart was used to verify the linear relationship between the variables and it was partially given. The independence of the residuals was judged by Durbin-Watson values of 1.51 and 1.85. Values ≈ 2 indicate the absence of autocorrelation of the residuals. A Probability-Probability-Plot (P-P-Plot) and a histogram were used to visually check for the normal distribution of the standardized residuals. For the question 1, both the Shapiro-Wilk-test and the Kolmogorov-Smirnov-test were statistically non-significant. Normal distribution of the residuals was not given for question 2, therefore bootstrapping (with 1000 samples) was used for the regression analysis. This method produces robust statistical results. With a scatterplot chart the homoscedasticity was verified, there was no recognizable pattern (Field, 2018).

The PROCESS-Tool Version 4.2 for SPSS (Hayes, 2022) was used to investigate for moderation effects (question 1b) in the course of a moderation analysis. Since the sample size

was >30 a normal distribution of the measurements of both variables and the normal distribution of the residuals was given (Field, 2018). The relation between the variables was checked visually and it seemed more or less linear. The moderation analysis with the PROCESS-Tool of Hayes controls for heteroskedasticity with the use of robust estimators. Additionally, the PROCESS-Tool automatically centers variables to account for the problem of multicollinearity (Hayes, 2022).

Analogous to the moderation analysis, the mediation analysis to investigate whether there was a mediating effect (question 1b) was executed with the PROCESS-Tool. The absence of multicollinearity is no precondition for the mediation analysis. The linearity of the relation was visually controlled with a scatterplot chart. The normal distribution of the residuals was verified, and it was accounted for possible heteroscedasticity.

Since the sample size was >30 it was possible, based on the central limit theorem, to accept the violation of the precondition of the normal distribution (Field, 2018).

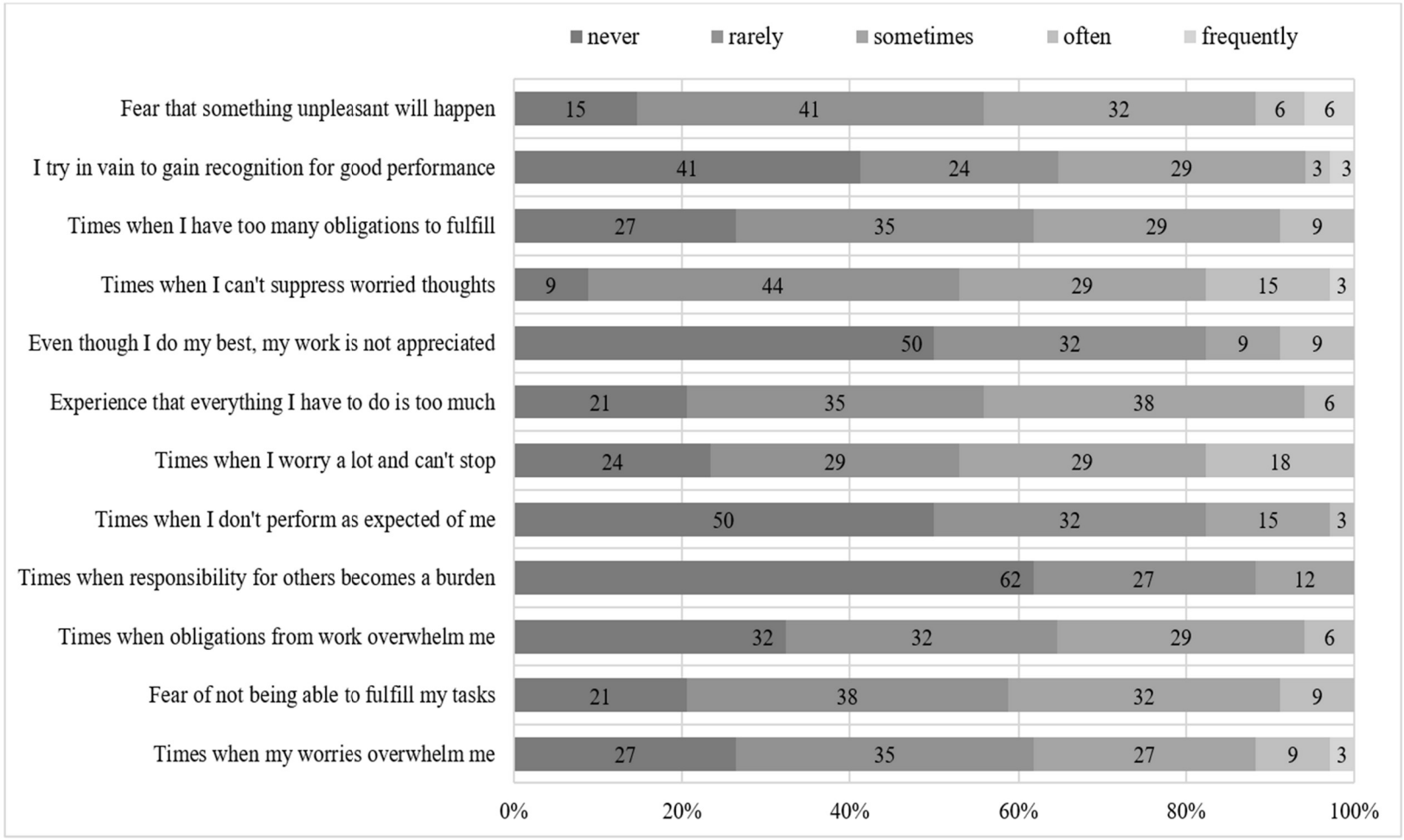
Results

The mean level of the reported chronic stress in the sample (SSCS-sum score) was 13.62 (*SD* = 8.12), the respective normed t-values had a mean of 47.56. Figure 7 shows the distributions of the response characteristics per item for the SSCS.

In a German, representative population survey by the DAK-Gesundheit (Marschall, 2014) the SSCS was used to assess the chronic stress. Women from 25-34 years reported a higher chronic stress than the current sample. The SSCS-sum score of women of 25-29 was 21.0 (*n* = 465) while the SSCS-sum score of women of 30-34: was 20.2 (*n* = 489) (Marschall, 2014).

Figure 7

SSCS: distribution of the item response characteristics in %



Note. Response characteristics in whole-number percentages. $n = 34$.

Regarding the good mood-bad mood scale, the participants had a mean score of 4.43 (*SD* = .54), while their mean baseline subjective stress level was at 17.91 (*SD* = 16.75) (see Table 2).

Table 2

Descriptive statistics for the scales good mood-bad mood (MDBF) and baseline subjective stress (VAS)

	good mood-bad mood	baseline subjective stress
N	33	33
M	4.43	17.91
Md	4.50	16.00
SD	.54	16.75
Min	2.75	0
Max	5.00	74

The mean skin barrier integrity ($TEWL_{baseline}$) of the sample was 15.65 (*SD* = 2.5). In regards to the skin barrier recovery (SBR), the mean SBR_1 of the sample was 26.72 (*SD* = 2.5), the mean SBR_2 33.67 (*SD* = 16.21), the mean SBR_3 33.55 (*SD* = 13.77) and the mean SBR_4 35.95 (*SD* = 15.44).

Table 3

Descriptive statistics for chronic stress (SSCS) and SBR

	SSCS			SBR				
	sum score	scale value	T-value	TEWL_ baseline	SBR_1	SBR_2	SBR_3	SBR_4
n	34	34	34	34	34	34	34	34
M	13.62	1.13	47.56	16.03	26.72	33.67	33.55	35.95
Md	14.00	1.17	50.50	15.55	25.90	36.55	33.65	37.05
SD	8.12	.68	11.66	2.28	12.20	16.21	13.77	15.44
min	0	0	15	12.5	3.2	5.0	6.3	1.7
max	29	2.42	64	22.8	52.8	73.1	55.1	70.3

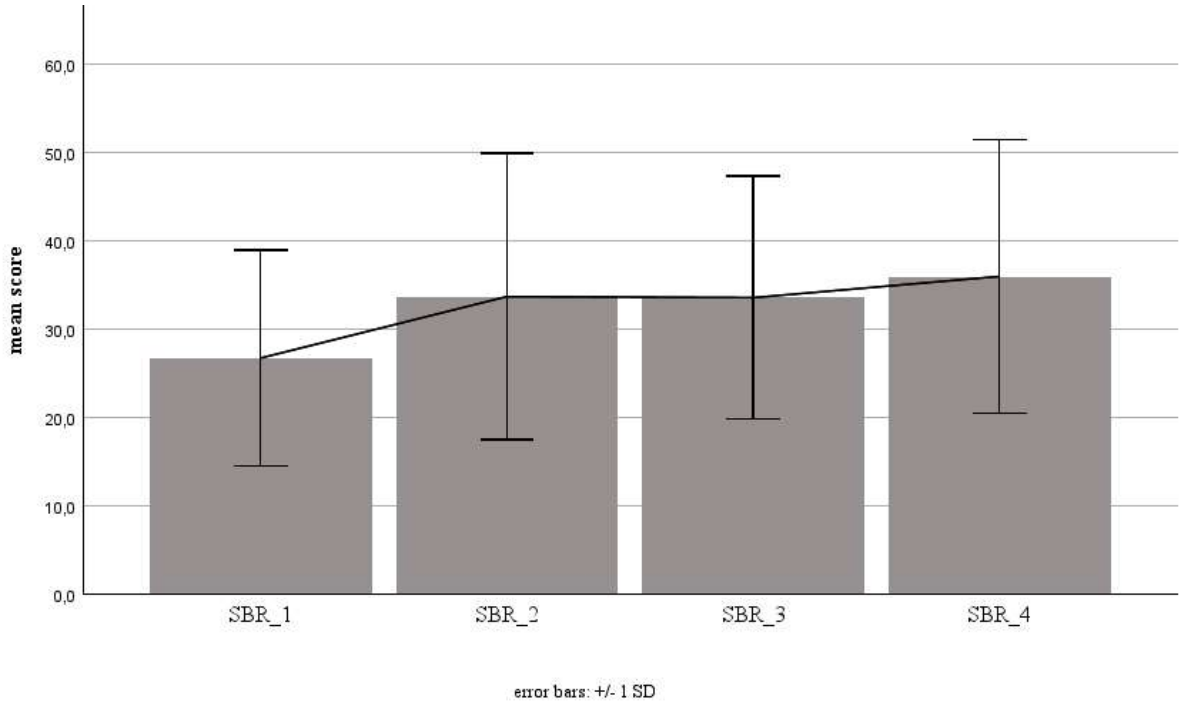
Note. TEWL_baseline refers to the TEWL measurement prior to tape stripping. The SBR was calculated at 4 times – SBR_1 is the skin barrier recovery 55 minutes, SBR_2 85 minutes, SBR_3 115 minutes and SBR_4 145 minutes post to tape stripping.

A detailed view of the data is provided in Table 3. Furthermore, the course of the mean SBR values is shown in Figure 8. Figure 8 shows, that the course of the SBR reaches a plateau

after SBR_2. The biggest difference between two following SBR values is between SBR_1 and SBR_2. In alignment with prior research (Robles et al., 2009) the skin barrier recovery is the most distinct during the first 1.5 hours post to tape stripping. Therefore the SBR_2 value will be used for the following analysis.

Figure 8

Display of the SBR-values in the course of time



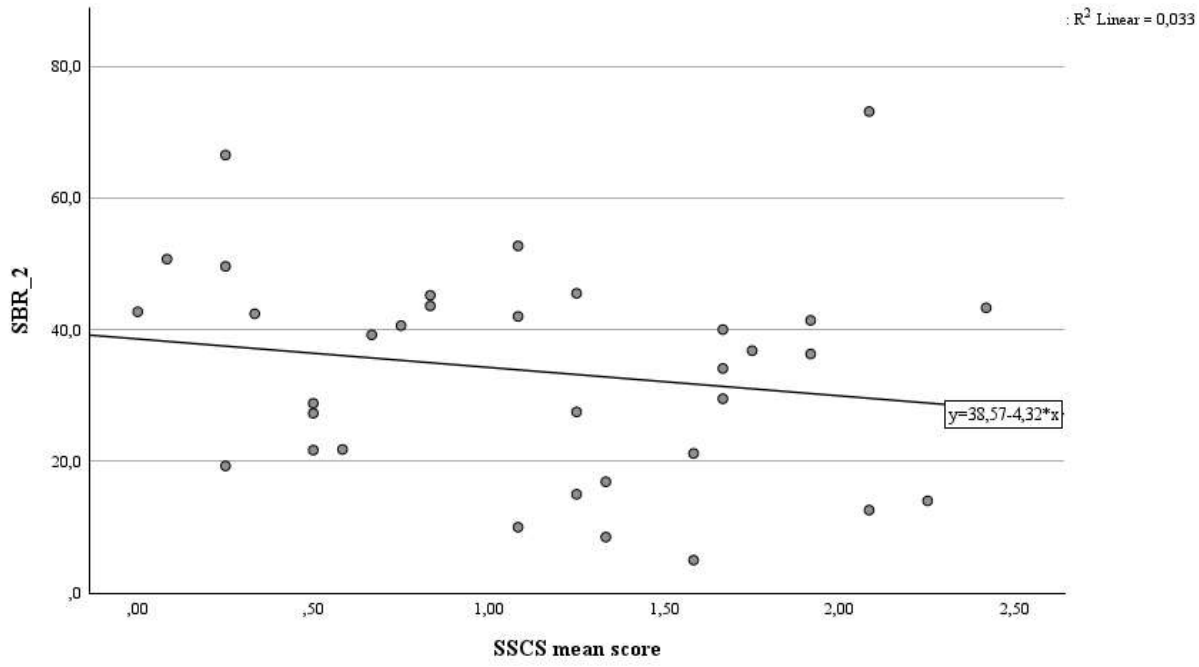
Note. TEWL values were measured at 4 distinct times to calculate SBR. SBR_1 for 4 distinct times – SBR_1 is the skin barrier recovery 55 minutes, SBR_2 85 minutes, SBR_3 115 minutes and SBR_4 145 minutes post to tape stripping.

Question 1: Relation between Chronic Stress and SBR

As expected, the chronic stress of the participants correlated negatively with the SBR. The correlation was weak with a correlation coefficient *r* of -.18. The correlation was not significant (p = .31). The variable SSCS was the independent variable, while SBR_2 was the dependent variable for the model of the used linear regression analysis. The proportion of the variation in SBR_2 variable that is predictable from SSCS R^2 was only 3.3%. Figure 9 shows the scatterplot chart for the relation between SSCS and SBR. The negative regression line is relatively flat (B = -4.32). The analysis of variance showed that the model is not significant (F (1, 32) = 1.076, p = .307). Therefore, the hypothesis regarding question 1 cannot be confirmed. It must be assumed, that chronic stress has no effect on SBR in the present sample.

Figure 9

Scatterplot chart of the relation between SSCS and SBR

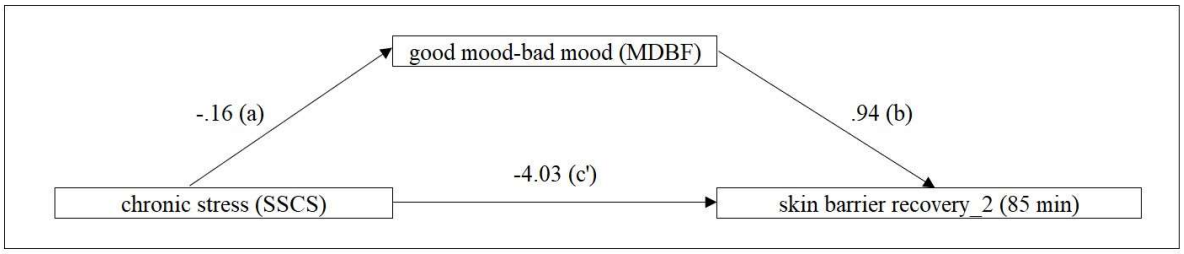


Question 1a: Mediation Analysis for SBR

To answer the question 1a, the effect of chronic stress on the SBR in consideration of a mediating effect of the present mood of the participants was investigated. Figure 10 depicts the mediation analysis according to model 4 of Hayes (Hayes, 2022).

Figure 10

Mediation analysis in accordance with model 4 of Andrew F. Hayes



The direct effects model of chronic stress on the present mood (path a) had no significant explanative value with $F(1,31) = 1.42$, $p = .24$. Further, the model investigating the direct effects of SCSS on SBR_2 and the effects of the present mood (good mood-bad mood as mediator) on SBR_2 (path c' and b) was with $F(2, 30) = .36$, $p = .70$ did not show significant results. A further interpretation of the mediation analysis is not relevant, since the chronic stress and the

present mood have no combined explanatory value regarding SBR_2. Therefore, hypothesis for question 1a has to be rejected.

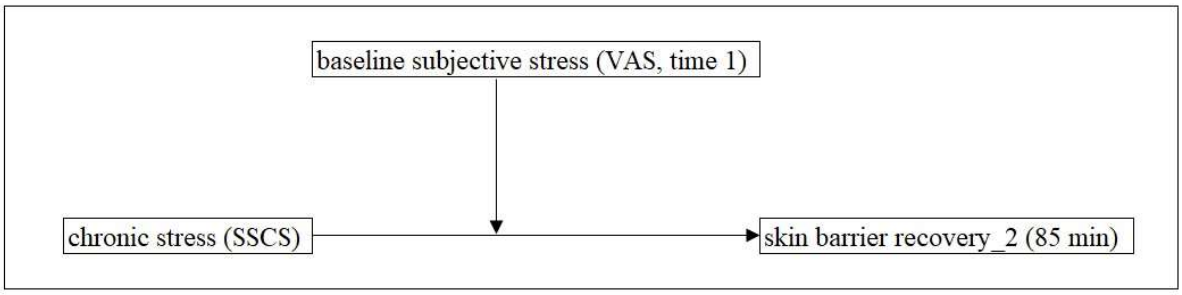
Question 1b: Moderation Analysis for SBR

To examine question 1b a moderation analysis was conducted. The aim was to investigate whether the relationship between chronic stress and SBR is moderated by the participants current stress level at the start of the laboratory appointment (baseline subjective stress). To analyse a possible moderation the *Mean and +/- One SD on M* method was used. The mentioned method is used to analyse the influence of the independent variable onto the dependent variable in 3 distinct manifestations of the moderator variable: below average (-1 *SD*), average (*M*) and above average (+1 *SD*).

The dependent variable was the SBR_2, 85 minutes post to tape stripping, while SSCS and baseline subjective stress, as well as their interaction were used as predictors. Figure 11 shows the resulting moderation analysis according to Hayes model 1 (Hayes, 2022).

Figure 11

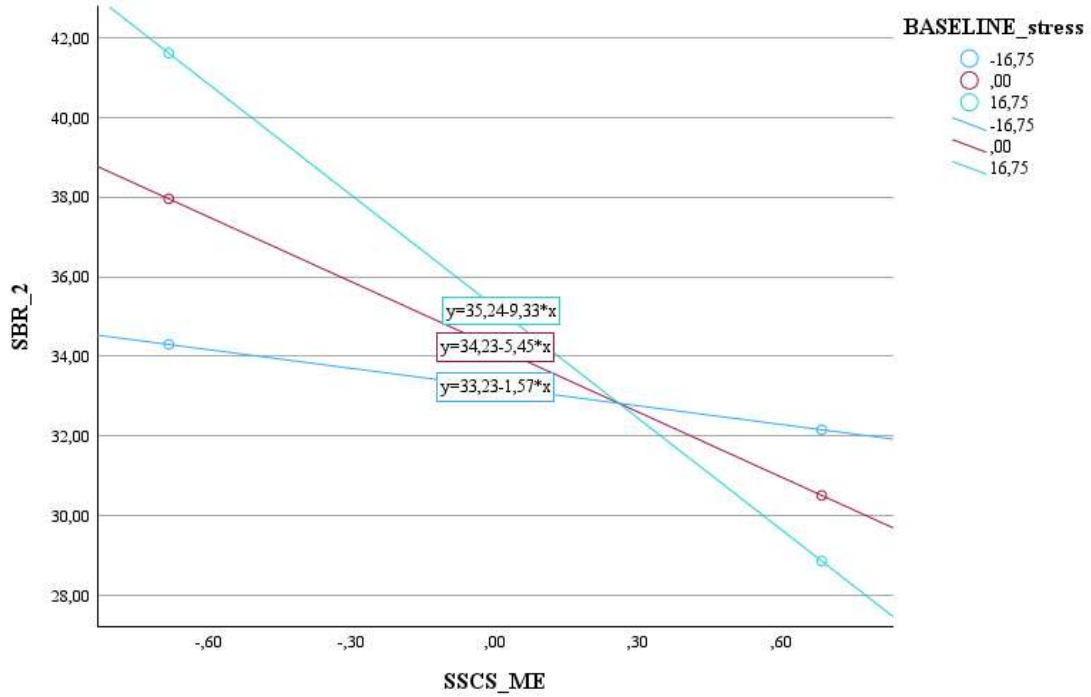
Moderation analysis in accordance with model 1 of Andrew F. Hayes



The results of the moderation analysis did not indicate any moderation effects of baseline subjective stress onto the relationship between chronic stress and SBR ($p > .05$). The resulting model was not significant, $F(3, 29) = .22$, $p = .88$, with an explained variation $R^2 = 4.7\%$. The model interpretation had to be stopped at this point. Figure 12 shows the according bivariate scatterplot chart.

Figure 12

Bivariate scatterplot chart for the relationship between chronic stress and the SBR under the moderation of baseline subjective stress



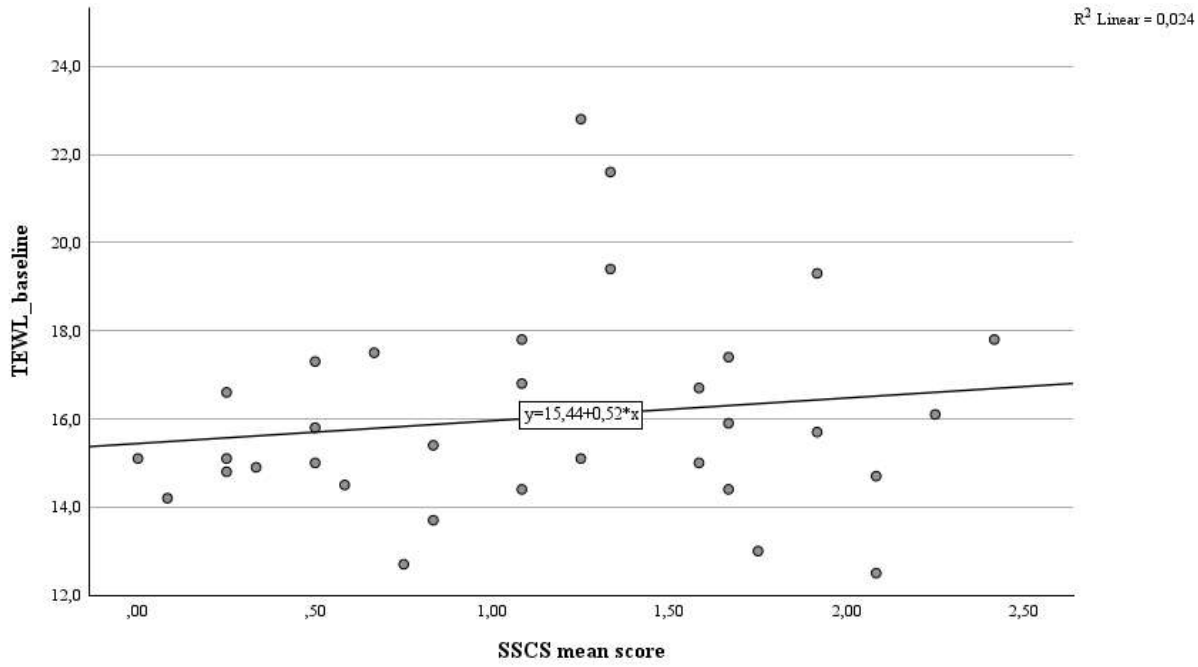
Note. Results of the moderation analysis (according to A. Hayes (2017), model 1): the moderation variable baseline subjective stress is shown with a manifestation below average (-1 SD), average (M) and above average (+1 SD) respectively. *n* =33 (exclusion of 1 case).

Question 2: Relation between Chronic Stress and SBI

To examine the relation between chronic stress and skin barrier integrity (SBI) a linear regression analysis with bootstrapping was performed. The level of chronic stress served as the model's independent variable, while the skin integrity served as the dependent variable. The correlation between the variables was weak and positive (r = .15) and not significant (p = .39). The explained variation by the predictor SSCS was only 2.4%. In Figure 12 the scatterplot chart of the relation between chronic stress and skin barrier integrity is shown. The regression line is very flat and has, as predicted, a positive slope (B = .52). The model was not significant with F (1,32) = .77, p = .39. Therefore, the hypothesis of question 2 can not be affirmed. Within the present sample, it must be assumed that chronic stress has no effect onto the skin integrity.

Figure 13

Scatterplot chart of the relation between SSCS and SI



Discussion

The aim of the present thesis was to examine whether chronic stress has an impact on the SBR. Based on other research about stress and tape stripping (Altemus et al., 2006; Garg et al., 2001 Muizzuddin et al., 2003; Robles, 2007) a negative influence of chronic stress onto the SBR was assumed. No significant effect was found.

Further two explorative analyses were conducted. The first one was investigating in a possible mediating effect of present mood on the effect of chronic stress on SBR. The model of the mediation analysis which tested these effects did not show significant results.

The second explorative analysis was examining whether baseline subjective stress acts as a moderator on the effect of chronic stress on SBR. Since acute stress is known to cause a delay in skin barrier recovery (Walburn et al., 2009), a moderating role of baseline subjective stress was assumed, but not found in the moderation analysis.

As a secondary question the relationship between chronic stress and SBI was tested. Research suggests a negative correlation between stress and SBI (Altemus et al., 2001; Choe et al., 2018; Choe et al., 2018). In the present analysis no such correlation was found. In the following a detailed view of the results of the respective research questions will be given.

Question 1: Chronic stress and SBR

Chronic stress and skin barrier recovery did not show a significant correlation. The hypothesis H (1.1) "chronic stress delays the regeneration of the stratum corneum" had to be dismissed. The biphasic model (Dhabhar & McEwen; 1997) states, that acute stress enhances, and chronic stress supresses the immune response. Nevertheless, acute stressors have been proven many times to delay the SBR (Altemus et al., 2001; Robles, 2007; Robles et al., 2009). In light of the biphasic model and the evidence that acute stressors can trigger a significant decrease in SBR, a significant delay in SBR was expected in the case of chronic stress. According to my data there is no significant relationship between chronic stress, as it's measured by the SSCS, and SBR. Both, the meta-analysis of Segerstrom and Miller (2004) and the meta-analysis of Zorilla et al. (2001) found contrary effects, proving the immunological consequences of chronic stressors. There are several possible reasons for the absence of an effect. First, the small sample size was relatively small and the power therefore possibly too low to detect an effect. Further, the participants of the study were homogenous and relatively low in their level of chronic stress. It is possibly due to that, that no effect was found. From the present sample no information about the skin barrier recovery of more chronically stressed persons can be obtained. The error-prone TEWL measurements and the assessment of chronic stress with the 12-item screening scale might be further reasons for the results of the present analysis present. Those weaknesses will be listed and discussed in more detail later (see Limitations).

Altemus and colleagues (2006) found an increased SBR rate in a sample, diagnosed with PTSD. They argue that persons with PTSD often show a disturbed function of the HPA-axis which leads to a disturbed immunological response. It could be possible that the immunological response of chronically stressed persons is disturbed too and that they show different SBR dynamics than persons with acute stress because of that.

Question 1a: Mediating Role of the Present Mood on the Effect of Chronic Stress on SBR

The first explorative analysis within the main research question was whether present mood mediates the effect of chronic stress on the recovery of the stratum corneum. The hypothesis H(1a.1) "the present mood mediates the effect of chronic stress on the recovery of the stratum corneum" had to be discarded. Neither the model investigating the effect of chronic stress on the present mood, nor the model investigating the direct effects of chronic stress on SBR and the effects of the present mood on the SBR were significant.

Although Robles (2009) found a positive impact of trait positive affect onto wound healing and Cole-King and Harding (2001) found evidence for delayed wound healing being associated with depression and anxiety, it seems that the present mood has no mediating effect between chronic stress and the SBR.

Apart from the fact that there could be no effect, there are various restrictions that could be to blame for not being able to prove an existing effect. Again, these findings could be attributable to the small sample size, and flawed TEWL measurements. For a detailed discussion of those restrictions will be see Limitations.

Question 1b: Moderating Role of baseline subjective Stress on the Effect of Chronic Stress on SBR

The second explorative question was the analysis of a possible moderating role of baseline subjective stress between the two main variables chronic stress and SBR. The moderation analysis did not yield any significant moderation effects of baseline subjective stress onto the relationship between chronic stress and SBR. Therefore, the hypothesis H (1b.1) "perceived stress increases the effect of chronic stress on the recovery of the stratum corneum" had to be rejected.

This finding has to be interpreted carefully in consideration of the small sample size. It is possible, that this result does not hold for a larger sample with a higher and more heterogenous chronic stress level. Further the accuracy of the participants baseline subjective stress assessment and the reliability of the TEWL measurements are questionable.

The assessment of the actual stress through the analysis of the participants salivary cortisol could lead to more objective findings of the role of the momentary stress level in the relationship between chronic stress and SBR. Even though saliva samples were taken from the participants, those samples were not yet analysed when the present thesis was written. More methodological limitations regarding question 1b will be specified in Limitations.

There might be other, unknown, moderating influencing factors in the relationship between chronic stress and SBR, which were not included in the present thesis. Personal coping strategies and psychological resilience could possibly have major impacts onto the relationship between chronic stress and SBR. A further analysis of other possible factors would have gone beyond the scope of this work.

Question 2: Relation between Chronic Stress and Skin Barrier Integrity

The secondary research question was investigating the influence of chronic stress on the skin barrier integrity. A linear regression analysis with the level of chronic stress as independent

variable and the skin integrity as dependent variable showed a positive but weak correlation between the variables. Since the analysis yielded no significant results the hypothesis H(2.1) “persons with high chronic stress show lower skin barrier integrity compared to persons with low chronic stress” had to be dismissed.

These results are surprising since previous research has shown that SBI is affected negatively by different kinds of stress (Altemus et al., 2001; Choi et al., 2005; Choe et al., 2018). Similar to the results of question 1 it is with regard to question 2 also questionable whether the measurements of chronic stress and skin parameters were reliable enough to identify a correlation. The low sample size is another reason to be careful when interpreting this result. It can be due to the a low chronic stress level in the sample, that no effects were found. No insights about how chronic stress affects skin barrier integrity in a more chronically stressed sample can be concluded.

Limitations

There are several major limitations restricting the quality of the present analysis. First, the limitations resulting from the sample and the various inclusion criteria, that had to be met to partake in the study, will be discussed. After that a more detailed view on the limitations, originating from the used materials and the procedure itself, will be provided.

The long list of inclusion criteria (see Appendix A) combined with the COVID-19 pandemic led to a relatively small number of participants. Due to those factors, the generalizability of the results is not given for a different population. Small sample sizes reduce the probability of identifying effects, even if they exist. The lack of significant effects could be resulting from the small sample size. Another factor, adding to the small sample size, was the reliability of the TEWL measuring procedure. The datasets of 22 participants had to be excluded from the analysis due to flawed measurements.

The sample of the present study was homogenous regarding its sex and age. The young women, that were tested to answer the research questions, also had similar educational levels and occupation situations. Their countries of origin were mostly middle European. Being fluent in German language was another factor adding to the homogeneity of the sample.

Chronic stress was relatively low within the sample, therefore no information about how the skin barrier would recover in a more chronically stressed population can be obtained from the present data. Furthermore, the sample was homogenous regarding their perceived stress, stating relatively low baseline subjective stress values on the VAS.

The sensitivity of the TEWL measurements makes them prone to various errors, such as humidity or temperature induced errors or errors caused by the participants (e.g., touching

the measurement site). Sweating represents another big impact onto TEWL values. Although the room temperature was kept constant, a measurement error in the TEWL values due to transpiration cannot be ruled out.

Chronic stress was assessed with a 12-item screening scale through self-assessment of the participants. It remains unclear how reliable the actual chronic stress is represented through that short self-assessment screening scale. There's a possibility that the participants tended to socially desirable response behaviour and stated lower chronic stress than they actually have.

Not only the homogeneity, as described above, but also the heterogeneity of the sample can make it difficult to test correlations with such a small sample size. Individual participants can differ greatly in their stress response due to genetic factors, lifestyles and other influencing factors like diet and physicality. Further personality traits and coping mechanisms were proven to moderate immunological responses to stress (Segerstrom & Miller, 2004).

All these influencing factors could lead to a certain variance that influences the statistical significance. Only with a very big sample size, or by controlling them, these factors could be averaged out.

More limitations of the present study result from the design of the research project it is embedded in. Participants were assigned to three groups: *music listening*, *audiobook* and *silence*. Because it is assumed that the participants in the music condition show a faster SBR than the other two groups, a confounding influence of those groups onto the SBR data used in the present analysis is possible. In order to control for the possibility of a confounding influence by the condition, the effects of the respective conditions should have been adjusted.

Due to the COVID-19 restrictions the research procedure was changed several times. In times of many infections, participants and researchers wore masks when they had social contact. Since social contact has proven to be an influential factor in SBR (Robinson et al., 2017), therefore it is possible that the effects are confounded by having limited facial feedback due to the masks.

Implications for Future Research

Even if the present sample did not show significant correlations. It seems that there is a negative correlation between chronic stress and SBR. Future research should investigate this correlation more closely. Further causes of delayed wound healing should be determined to gather knowledge for developing possibilities for interventions. Within the clinical context it is very important to identify factors, which improve wound healing. With sufficient knowledge, doctors can develop strategies to better treat patients with larger wounds, such as burns, and ensure faster wound healing. Interventions to reduce the patient's psychological stress level may

improve wound healing and recovery after surgery. Future research should investigate the role of common relaxation and stress management techniques on skin barrier recovery.

As stated above it might be important to examine the role of genetic predispositions and their role in the relationship between stress and wound healing. Some people may have genetic predispositions to cope more robustly with stress, while others may be more susceptible to the negative effects of stress. It is important to know how to provide the best conditions for effective wound healing for the latter. Furthermore, differences in lifestyle, including diet, sleep habits, physical activity and other behaviours, could affect the response to stress and overall health, including wound healing. To get a better understanding, those interpersonal differences can be included in the analyses of future studies.

Since the SBR data of each participant in the present study was gathered within one afternoon it would be informative how chronic stress impacts wound healing over a longer period of time. Future studies could examine the same sample over weeks or even months to gain more knowledge about the specific connections between the variables. Additionally, to ensure better generalizability, a more diverse population should be studied.

Conclusion

In the present analysis no effect of chronic stress on SBR was found. Further there were no effects found in the two explorative analyses, investigating the mediating role of present mood and the moderating role of baseline subjective stress on the effect of chronic stress on SBR. In addition, no significant correlation was found between chronic stress and SBI. The absence of these effects is possibly due to the small sample size. Although the generalizability of the findings is limited by the small sample and several limitations restrict the quality of the present analysis, this study is another important step into the right direction of identifying mechanisms how stress impacts the body.

The present study adds to the body of research investigating the effects of psychological stress on physical health and well-being. Since our lives are getting more and more complex and people are increasingly confronted with new types of stressors, the importance of research about the impact of stress grows more important as well. Only with detailed knowledge about the ways in which stress affects our body and mind it is possible to provide techniques and strategies to reduce both stress and its hazardous effects on our well-being.

References

Ader, R., Felten, D., & Cohen, N. (1990). Interactions between the brain and the immune system. *Annu. Rev. Pharmacol. Toxicol*, *30*, 561–602. www.annualreviews.org

Allen, M. T., Stoney, C. M., Owens, J. F., & Matthews, K. A. (1993). Hemodynamic Adjustments to Laboratory Stress: The Influence of Gender and Personality. *Psychosomatic Medicine*, *55*(6), 505–517. https://doi.org/10.1097/00006842-199311000-00006

Almeida, D. M., Charles, S. T., Mogle, J., Drewelles, J., Aldwin, C. M., Spiro, A., & Gerstorf, D. (2020). Charting adult development through (historically changing) daily stress processes. *American Psychologist*, *75*(4), 511–524.

Altemus, M., Dhabhar, F. S., & Yang, R. (2006). Immune function in PTSD. *Annals of the New York Academy of Sciences*, *1071*, 167–183. https://doi.org/10.1196/annals.1364.013

Altemus, M., Rao, B., Dhabhar, F. S., Ding, W., & Granstein, R. D. (2001). Stress-induced changes in skin barrier function in healthy women. *Journal of Investigative Dermatology*, *117*(2), 309–317. https://doi.org/10.1046/j.1523-1747.2001.01373.x

Bartlett, J. D., Griffin, J., & Thomson, D. (2020). Resources for supporting children's COVID-10 Pandemic emotional well-being. *Child Trends*, 4–6.

Baum, A., Cohen, L., & Hall, M. (1993). Control and Intrusive Memories as Possible Determinants of Chronic Stress. *Psychosom Med.*, *55*(3), 274–286. https://doi.org/10.1097/00006842-199305000-00005

Bear, M., Connors, B., & Paradiso, M. (2007). *Neuroscience*. Lippincott Williams & Wilkins.

Beck, A. T., Steer, R. A., & Brown, G. K. (1996). *Beck Depression Inventory (BDI-II)*. Springer.

Becker, P., Schulz, P., & Schlotz, W. (2004). Persönlichkeit, chronischer Stress und körperliche Gesundheit. *Zeitschrift Für Gesundheitspsychologie*, *12*(1), 11–23. https://doi.org/10.1026/0943-8149.12.1.11

Broadbent, E., Petrie, K. J., Alley, P. G., & Booth, R. J. (2003). Psychological stress impairs early wound repair following surgery. *Psychosomatic Medicine*, *65*(5), 865–869. https://doi.org/10.1097/01.PSY.0000088589.92699.30

Chiang, N. Y. Z., & Verbov, J. (2020). *Dermatology: Handbook for medical students & junior doctors*. British Association of Dermatologists.

Choe, S. J., Kim, D., Kim, E. J., Ahn, J. S., Choi, E. J., Son, E. D., Lee, T. R., & Choi, E. H. (2018). Psychological Stress Deteriorates Skin Barrier Function by Activating 11β-

Hydroxysteroid Dehydrogenase 1 and the HPA Axis. *Scientific Reports*, *8*(1). https://doi.org/10.1038/s41598-018-24653-z

Choi, E.-H., Brown, B. E., Crumrine, D., Chang, S., Man, M.-Q., Elias, P. M., & Feingold, K. R. (2005). Mechanisms by Which Psychologic Stress Alters Cutaneous Permeability Barrier Homeostasis and Stratum Corneum Integrity. *Journal of Investigative Dermatology*, *124*(3), 587–595.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (Vol. 2). Psychology Press.

Cohen, S., Kamarck, T., & Mermelstein, R. (1983). A global measure of perceived stress. *Journal of Health and Social Behavior*, *24*(4), 386–396.

Cole-King, A., & Harding, K. G. (2001). Psychological Factors and Delayed Healing in Chronic Wounds. *Psychosomatic Medicine*, *63*, 216-220.

Costa, P. T., & McCrae, R. R. (1992). *Revised NEO Personality Inventory (NEO-PI-R) and NEO Five-Factor Inventory (NEO-FFI) Professional Manual*. Psychological Assessment Resources.

Dhabhar, F. S., & McEwen, B. S. (1997). Acute Stress Enhances while Chronic Stress Suppresses Cell-Mediated Immunity in Vivo: A Potential Role for Leukocyte Trafficking. *BRAIN, BEHAVIOR, AND IMMUNITY*, *11*, 286–306.

Ditzen, B., & Nater, U. M. (2006). Klinisches Untersuchungsverfahren. *Zeitschrift Für Klinische Psychologie Und Psychotherapie*, *35*(3), 241–242. https://doi.org/10.1026/1616-3443.35.3.241

Elliot, G. R., & Eisdorfer, C. (1982). *Stress and Human Health*. Springer.

Engebretsen, K. A., Johansen, J. D., Kezic, S., Linneberg, A., & Thyssen, J. P. (2016). The effect of environmental humidity and temperature on skin barrier function and dermatitis. In *Journal of the European Academy of Dermatology and Venereology* (Vol. 30, Issue 2, pp. 223–249). Blackwell Publishing Ltd. https://doi.org/10.1111/jdv.13301

Field, A. (2018). *Discovering statistics using IBM SPSS statistics* (Vol. 5). SAGE.

Fiorillo, A., & Gorwood, P. (2020). The consequences of the COVID-19 pandemic on mental health and implications for clinical practice. *European Psychiatry*, *63*(1). https://doi.org/10.1192/j.eurpsy.2020.35

Gallucci, R. M., Simeonova, P. P., Matheson, J. M., Kommineni, C., Guriel, J. L., Sugawara, T., & Luster, M. I. (2000). Impaired cutaneous wound healing in interleukin-6-deficient and immunosuppressed mice. *FASEB J*, *14*, 2525–2531.

Garg, A., Chren, M.-M., Sands, L. P., Matsui, M. S., Marenus, K. D., Feingold, K. R., & Elias, P. M. (2001). Psychological Stress Perturbs Epidermal Permeability Barrier Homeostasis Implications for the Pathogenesis of Stress-Associated Skin Disorders. *Arch Dermatol*, *137*, 53–59. http://archderm.jamanetwork.com/pdfaccess.ashx?url=/data/journals/derm/11694/

Gerrig, R. J., & Zimbardo, P. G. (2007). *Psychology and Life* (18th ed.). Pearson Education.

Gilbert, P., McEwan, K., Mitra, R., Franks, L., Richter, A., & Rockliff, H. (2008). Feeling safe and content: A specific regulation system? Relationship to depression, anxiety, stress and self-criticism. *The Journal of Positive Psychology*, *3*, 182–191.

Glaser, R., Kiecolt-Glaser, J. K., Marucha, P. T., Maccallum, R. C., Laskowski, B. F., & Malarkey, W. B. (1999). Stress-Related Changes in Proinflammatory Cytokine Production in Wounds. *Arch Gen Psychiatry*, *56*(5), 450–456. https://doi.org/10.1001/archpsyc.56.5.450

Gouin, J. P., Carter, C. S., Pournajafi-Nazarloo, H., Glaser, R., Malarkey, W. B., Loving, T. J., Stowell, J., & Kiecolt-Glaser, J. K. (2010). Marital behavior, oxytocin, vasopressin, and wound healing. *Psychoneuroendocrinology*, *35*(7), 1082–1090. https://doi.org/10.1016/j.psyneuen.2010.01.009

Gouin, J. P., & Kiecolt-Glaser, J. K. (2011). The Impact of Psychological Stress on Wound Healing: Methods and Mechanisms. *Immunology and Allergy Clinics of North America*, *31*(1), 81–93. https://doi.org/10.1016/j.iac.2010.09.010

Hänel, K. H., Cornelissen, C., Lüscher, B., & Baron, J. M. (2013). Cytokines and the skin barrier. *International Journal of Molecular Sciences*, *14*(4), 6720–6745. https://doi.org/10.3390/ijms14046720

Hans Selye. (1976). Stress without Distress. In L. Levi (Ed.), *Society, stress and disease* (Vol. 5, pp. 137–146). Oxford University Press. https://doi.org/10.1007/978-1-4684-2238-2_9

Hayes, A. F. (2017). *Introduction to mediation, moderation, and conditional process analysis. A regression-based approach* (2nd ed.). The Guilford Press.

Hayes, A. F. (2022). *Introduction to Mediation, Moderation, and Conditional Process Analysis* (3rd ed.). Guilford Press.

Hübner, G., Brauchle, M., Smola, H., Madlener, M., Fässler, R., & Werner, S. (1996). Hübner pro inflammatory cytokines and gluccocorticoid wound healing mice 1996. *Cytokine*, *8*(7), 548–556. https://doi.org/10.1006/cyto.1996.0074

Hunter, H. J. A., Momen, S. E., & Kleyn, C. E. (2015). The impact of psychosocial stress on healthy skin. *Clinical and Experimental Dermatology*, *40*(5), 540–546. https://doi.org/10.1111/ced.12582

Jones, F., Bright, J., & Clow, A. (2001). *Stress: Myth, Theory and Research*. Pearson Education.

Kirschbaum, C., Pirke, K. M., & Hellhammer, D. H. (1993). The "Trier Social Stress Test" - a tool for investigating psychobiological stress responses in a laboratory setting. *Neuropsychobiology*, *28*(1–2), 76–81.

Kreutz, G., Schubert, E., & Mitchell, L. A. (2008). Cognitive styles of music listening. *Music Perception*, *26*(1), 57–73.

Lazarus, R. S., & Folkman, S. (1984). *Stress, Appraisal and Coping*. Springer.

Löwe, B., Spitzer, R. L., Zipfel, S., & Herzog, W. (2002). *Prime MD Patient Health Questionnaire (PHQ)*. Pfizer.

Marschall, J. (2014). *Belastung durch chronischen Stress Sonderauswertung der Befragung der DAK-Gesundheit im Rahmen des Schwerpunktthemas 2014 – „Rushhour des Lebens"*.

Mas-Herrero, E., Marco-Pallares, J., Lorenzo-Seva, U., Zatorre, R. J., & Rodriguez-Fornells, A. (2013). Individual differences in music reward experiences. *Music Perception*, *31*(2), 118–138.

McCarty, R. (2016). The Fight-or-Flight Response: A Cornerstone of Stress Research. In *Stress: Concepts, Cognition, Emotion, and Behavior: Handbook of Stress* (pp. 33–37). Elsevier. https://doi.org/10.1016/B978-0-12-800951-2.00004-2

Moosbrugger, H., & Kelava, A. (2012). *Testtheorie und Fragebogenkonstruktion*. Springer.

Muizzuddin, N., Matsui, M. S., Marenus, K. D., & Maes, D. H. (2003). Impact of stress of marital dissolution on skin barrier recovery: Tape stripping and measurement of trans-epidermal water loss (TEWL). *Skin Research and Technology*, *9*(1), 34–38. https://doi.org/10.1034/j.1600-0846.2003.00354.x

Nater, U., Krebs, M., & Ehlert, U. (2005). Sensation seeking, music preference and psychophysiological reactivity to music. *Musicae Scientiae*, *9*(2), 239–254.

Petrowski, K., Paul, S., Albani, C., & Brähler, E. (2012). Factor structure and psychometric properties of the Trier inventory for chronic stress (TICS) in a representative German sample. *BMC Medical Research Methodology*, *12*. https://doi.org/10.1186/1471-2288-12-42

Pinel, J. P. , J. (2006). *Biopsychology* (6th ed.). Pearson Education.

Robinson, H., Ravikulan, A., Nater, U. M., Skoluda, N., Jarrett, P., & Broadbent, E. (2017). The role of social closeness during tape stripping to facilitate skin barrier recovery: Preliminary findings. *Health Psychology*, *36*(7), 619–629. https://doi.org/10.1037/hea0000492

Robles, T. F. (2007). Stress, social support, and delayed skin barrier recovery. *Psychosomatic Medicine*, *69*(8), 807–815. https://doi.org/10.1097/PSY.0b013e318157b12e

Robles, T. F., Brooks, K. P., & Pressman, S. D. (2009). Trait Positive Affect Buffers the Effects of Acute Stress on Skin Barrier Recovery. *Health Psychology*, *28*(3), 373–378. https://doi.org/10.1037/a0014662

Rost, J. (2004). *Lehrbuch Testtheorie - Testkonstruktion* (Vol. 2). Verlag Hans Huber.

Saarikallio, S. (2012). Development and Validation of the Brief Music in Mood Regulation Scale. *Music Perception*, *30*(1), 97–105.

Salmon, J. K., Armstrong, C. A., & Ansel, J. C. (1994). The Skin as an Immune Organ. *West J Med*, *160*(2), 146–152.

Schulz, P., Schlotz, W., & Becker, P. (2004). *Trierer Inventar zum chronischen Stress (TICS)*. Hogrefe.

Segerstrom, S. C., & Miller, G. E. (2004). Psychological stress and the human immune system: A meta-analytic study of 30 years of inquiry. *Psychological Bulletin*, *130*(4), 601–630. https://doi.org/10.1037/0033-2909.130.4.601

Sivamani, R. K., Pullar, C. E., Manabat-Hidalgo, C. G., Rocke, D. M., Carlsen, R. C., Greenhalgh, D. G., & Isseroff, R. R. (2009). Stress-Mediated Increases in Systemic and Local Epinephrine Impair Skin Wound Healing: Potential New Indication for Beta Blockers. *PLoS Medicine*, *6*(1). https://doi.org/10.1371%2Fjournal.pmed.1000012

Skinner, N., & Brewer, N. (2002). The dynamics of threat and challenge appraisals prior to stressful achievement events. *Journal of Personality and Social Psychology*, *83*(3), 678–692. https://doi.org/10.1037/0022-3514.83.3.678

Steptoe, A., Wardle, J., & Marmot, M. (2005). Positive affect and health-related neuroendocrine, cardiovascular, and inflammatory processes. *PNAS May*, *3*(18), 6508–6512. https://doi.org/10.1073pnas.0409174102

Steyer, R., Schwenkmezger, P., Notz, P., & Eid, M. (1997). *Der Mehrdimensionale Befindlichkeitsfragebogen (MDBF)*. Hogrefe.

Takeda, T., Yoshimi, K., & Yamada, K. (2020). Psychometric Testing of the Premenstrual Symptoms Questionnaire and the Association Between Perceived Injustice and

Premenstrual Symptoms: A Cross-Sectional Study Among Japanese High School Students. *Int J Womens Health*, *12*, 755–763.

Tellegen, A., & Atkinson, G. (1974). Openness to absorbing and self-altering experiences ("absorption"), a trait related to hypnotic susceptibility. *J. Abnorm. Psychol.*, *83*, 268–277.

Tugade, M. M., & Fredrickson, B. L. (2004). Resilient Individuals Use Positive Emotions to Bounce Back From Negative Emotional Experiences. *Journal of Personality and Social Psychology*, *86*(2), 320–333. https://doi.org/10.1037/0022-3514.86.2.320

Walburn, J., Vedhara, K., Hankins, M., Rixon, L., & Weinman, J. (2009). Psychological stress and wound healing in humans: A systematic review and meta-analysis. *Journal of Psychosomatic Research*, *67*(3), 253–271. https://doi.org/10.1016/j.jpsychores.2009.04.002

Wheaton, B. (1997). The Nature of Chronic Stress. In B. H. Gottlieb (Ed.), *Coping with Chronic Stress* (pp. 43–74). Springer Science+Business Media.

Xin, S., Ye, L., Man, G., Lv, C., Elias, P. M., & Man, M. Q. (2016). Heavy Cigarette Smokers in a Chinese Population Display a Compromised Permeability Barrier. *BioMed Research International*, *2016*. https://doi.org/10.1155/2016/9704598

Zhen, W., Mao-Quiang, M., Tienan, L., Peter, E., & Theodora, M. (2020). Aging-associated alterations in epidermal function and their clinical significance. *Aging*, *12*(6).

Zorrilla, E. P., Luborsky, L., McKay, J. R., Rosenthal, R., Houldin, A., Tax, A., McCorkle, R., Seligman, D. A., & Schmidt, K. (2001). The relationship of depression and stressors to immunological assays: A meta-analytic review. *Brain, Behavior, and Immunity, 15*(3). https://doi.org/10.1006/brbi.2000.0597

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List of Abbreviations

Acronym	Description
α	Probability of accepting the alternative hypothesis, although the null hypothesis is true for the population (type 1 error), also used for the Cronbach‘s alpha coefficient (internal consistency)
d	Effect size for mean differences of 2 groups according to Cohen (1988)
η^2	Effect size for analysis of variance
r_{it}	Corrected item discriminatory power (part-whole correlation)
M	Mean
max	Maximum
Md	Median
min	Minimum
N, *n*	Sample size, partial sample size
p	Probability for a result in accord with the alternative hypothesis, although the null hypothesis is true in reality
%	Percentage
R^2	Goodness-of-fit value for regression models
r	Pearsons corelation coefficient
SBR	Skin barrier recovery
SBI	Skin barrier integrity
SSCS	Screening scale for chronic stress
SD	Standard deviation
TEWL	Transepidermal water loss
TICS	Trier inventory for chronic stress

Appendix A. List of Inclusion Criteria

Study 1 (without stressor)
General criteria / criteria for biomarker studies
Female
Age 18-35
Fluent in German
Non-smokers
No pregnancy, breastfeeding
Healthy, no current flu
No chronic somatic illnesses, including:
Allergies / hypersensitivity reactions (medicines, patches, latex gloves, hay fever, grasses, pollen)
Cardiovascular diseases (coronary heart disease, angina pectoris, myocardial infarction, cardiac arrhythmia, heart failure , Arterial occlusive diseases)
Pulmonary and respiratory diseases (pneumonia, asthma, chronic bronchitis, tuberculosis)
Liver diseases (hepatitis, jaundice, fatty liver)
Hypertension or extremely low blood pressure
Chronic pain
Kidney and urinary tract diseases (kidney / bladder stones)
Diabetes Mellitus or other metabolic diseases (hypercholesterolemia, hyperuricemia)
Diseases of the digestive tract (stomach diseases, chronic intestinal diseases)
Neurological diseases
Infectious diseases (e.g. HIV, Hep., TBC)
Thyroid abnormality
Autoimmune diseases
Diseases of the skeletal system / muscle diseases
Blood disorders (bruises develop without special cause, anemia)
No visual impairments (if not correctable with glasses or contact lenses)
No current mental disorder or psychiatric illness (depression, psychosis, anxiety disorders, eating disorders within the last 5 years)
No tropical stay in the last 6 months
No vaccinations the last 2 weeks
BMI: 18 – 25

No excessive alcohol use (substance abuse within the last 2 years, regular consumption ≥8)
No drug intake in the last year or cannabis in the past 14 days
No (dental) surgery in the last 8 weeks (narcosis, type of procedure, pending cure)
No other health-related anomalies (tumors, meningitis, accident, etc.)
No use of psychopharmaca in the past 14 days
No intake of cardiovascular medication (e.g. beta-blockers)
No use of medication that affects hormones
No hormonal contraception
Regular menstrual cycle
Music-related criteria
No hearing impairment or chronic tinnitus
No music-related profession / music related studies
No absolute hearing
Tape-stipping- specific criteria
No chronic or acute inflammatory skin diseases
No allergies to adhesive tape
No eczema/rashes, burn marks etc. on the volar forearm
No intake of immunosuppressive drugs (e.g. prednisone)