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What must one do to lead a stress-free life? Become a Stoic, or perhaps a monk? Perhaps an hour of meditation each day, followed by a deep tissue massage might help release the tension that has built up throughout a day. But what if there is a simpler way? What if merely moving more in our daily lives could lead us to going to bed with fewer burdens? To answer this question, this thesis will examine the relationship between daily physical activity and stress and will place particular importance on anticipatory stress as influence on this relationship. To establish the theoretical foundations of this thesis, I will commence by introducing the concept and history of stress, coping, and resilience. I will follow this by examining the concept of physical activity and any limitations that current research on this topic might show. The effect of physical activity on health is described, followed by the influence that physical activity may have on stress. This segues into a description of anticipatory stress and determining factors, and concludes in the formulation of research gaps, research questions, and hypotheses. Methods are described and results are presented, followed by the discussion, and lastly, a conclusion.

Theoretical Background

My aim for this study is to examine the relationship between physical activity and stress. Particularly, I am interested in how physical activity might influence the relationship between feeling stressed in anticipation of the day and feeling stressed at the end of the day. But before describing that specific sort of stress, I will more generally introduce and discuss stress.

Stress

Stress is ubiquitous and unavoidable in our daily lives. It is also a diffuse concept. A person unfamiliar with stress research might have some imagination of it but could find it difficult to articulate a concise definition. It might be described as the constricting feeling in one’s chest or head that blocks clear thinking. Stress might represent the feeling of tension and being overwhelmed that causes one to break out in a cold sweat. Another person might say that

stress is a biological response, and that cortisol plays an important role. Lastly, stress might be described as a state of being, something that one "has" or "is in". And so on.

For academic purposes, it is important to examine and define this concept more accurately. Stress was succinctly described to "not refer to a specific variable but [stress] is a general organizing concept for understanding a wide range of phenomena of great importance in human and animal adaptation." (Roskies, 1991, p. 418). Stress is less a symptom than it is a syndrome, made up of interconnected facets ranging from physiological to affective, to behavioral changes (Chrousos, 2009). This view is the result of a historical process. The word itself derives from the Latin language and would only start to gain its current meaning in the 19th century (Robinson, 2018). Physicians at the time noted that there were bodily functions working to maintain a stable and balanced internal environment, and that the body's reaction to the environment could lead to disease. Walter Cannon built on these earlier works to develop the theory of homeostasis. It describes the processes by which bodily systems maintain a stable internal state, which could be disturbed by outside forces. Hans Selye formalized the concept of a general physiological response to outside forces, naming it the "General Adaptation Syndrome" (GAS). Selye borrowed the term "stress" from physics and engineering (Lazarus & Folkman, 1984, p. 2), and later on renamed the GAS and referred to that concept as the term "stress response" (Robinson, 2018). The then prevalent paradigm of behaviorism excluded cognitive processes from this general reaction. Concepts such as the GAS were unable to explain why some stressful events could lead to severe stress responses such as shell shock, while others did not. Richard Lazarus, building on the work of Selye, focused on individual factors that could explain the dynamic nature of stress. He popularized the notion that the variance in stress responses stems from how individuals interpreted a given stimulus – In other words, how a person *thinks* about a stimulus can influence their reaction. He and his colleague further coined the concept of *coping*, describing how individuals *deal* with stress (Lazarus & Folkman, 1984; Robinson, 2018). The stimuli that elicit stress responses are referred to as "stressors" (e.g. Chrousos, 2009; Contrada & Baum, 2011). "Stress" mostly refers to the stress response, but still sometimes refers to stressors (Gutman & Nemeroff, 2011; Robinson, 2018). A stress response can include the subjective *feeling of stress,* mostly referred to as "perceived stress", but sometimes as just "stress" (Feneberg & Nater, 2020; Pulopulos et al., 2020). For the sake of clarity, this thesis will use "stressor" to refer to the stimuli that lead to a response, and "stress

response" will refer to the ways in which individuals react to a stressor. To put simply, stressors are what cause stress and stress responses are the outcome.

Transactional Model of Stress

Lazarus popularized the concept that the outcome of stress is influenced by how a person thinks of a stressor – How exactly does this process work? The Transactional Model of Stress (Lazarus & Folkman, 1984) revolves around this question, asking, "Does this situation pose danger to me and if it does, what can I do about it?"

According to this model, *appraisal* is the cognitive process by which an individual determines, consciously or subconsciously, if in a given a situation, stress is appropriate. In a first step, *primary appraisal*, it is determined if an event is irrelevant, beneficial, or stressful. According to Lazarus and Folkman (1984), stressful situations pose either harm or loss, threat, or challenge. Harm and loss occur in the past or present; threat lies in the future. For example, while a biting dog does pose harm right now, it may pose a future threat as well, as it may still launch another attack or pursuit. Challenges differ from threats in that they hold the potential for positive change, while threats are potential harms or losses. Nevertheless, threat and challenge are not binary, they are more accurately described by a spectrum. If a situation is appraised as stressful, *secondary appraisal* follows[1], in which one determines, consciously or subconsciously, what one can do in that situation. One's own resources might suffice; in which case the situation is regarded as under control. However, should it be determined that one does not have sufficient resources, a stress response is activated. This stress response leads to numerous bodily and mental changes that increase our ability to adapt to difficult and challenging situations. These changes are not initiated consciously. Conscious, effortful attempts to manage situations that are taxing or exceeding one's resources are referred to as coping (Lazarus & Folkman, 1984, p. 141). Coping has also been described as attempts of reducing subjective stress (Smith & Kirby, 2011). Behavior that attempts to but does not successfully decrease subjective stress is

[1] Primary and secondary appraisal influence each other, and one is not more important than the other. It is a simplification that has found its place in the literature and facilitates understanding of the theory.

still considered coping. This might include things such as devising a plan, smoking a cigarette – or engaging in physical activity. Lazarus and Folkman (1984) distinguish these behaviors into coping that aims to change the emotions associated with a stressor (emotion-focused coping), and coping that aims to change the problem itself (problem-focused coping). Other authors do not limit themselves to problem- and emotion-focused coping, and distinguish between approach and avoidance (Carver, 2011). While approach coping refers to dealing with the stressor or the emotions evoked by it, avoidance refers to disengagement, i.e., attempts to distract from, escape or ignore the stressor. Physical activity might be used to deal with stress-evoked emotions, or to distract from the stressor, and thus take on all these roles.

How does stress affect us?

Stress is the result of appraisal processes and can be dealt with via coping. Stress is also an umbrella term that includes many symptoms. Understanding how physical activity might influence stress requires us to know the different ways that stress expresses itself. The following section will discuss these.

On a biological and physiological level, there are three main systems associated with stress: the hypothalamus-pituitary-adrenal axis (HPA axis), the autonomous nervous system (ANS), and the immune system (Feneberg & Nater, 2020).

The HPA response originates in the hypothalamus, which secretes corticotropin-releasing-hormone. These hormones reach the pituitary gland, which secretes adrenocorticotropic hormone, which through the blood reaches the adrenal glands. There, the adrenocorticotropic hormone promotes the release of cortisol. Cortisol can be measured both in the blood and in the saliva. Cortisol levels rise and fall in a diurnal pattern, and have a distinct awakening response (Agorastos & Chrousos, 2022; Gaab et al., 2005). The cortisol awakening response is itself used as an indicator for physiological stress reactivity. Cortisol interacts with the central and peripheral nervous systems, as well as the immune system, leading to for instance rises in blood glucose or vasoconstriction. It acts on and moderates the function of other endocrine systems, and also inhibits its own secretion (Agorastos & Chrousos, 2022; Feneberg & Nater, 2020; Kemeny, 2003).

Of the autonomic nervous system, the sympathetic nervous system is of particular importance when it comes to stress responses, which is partially controlled centrally by the locus coeruleus. Under stress conditions, the stimulation of the sympathetic nervous system results in the secretion of catecholamines, i.e., norepinephrine and epinephrine. These hormones act on adrenergic receptors both centrally and peripherally and stimulate the HPA-axis as well, resulting in symptoms of raised blood pressure, heart rate, salivary flow, as well as changes in cognition (Agorastos & Chrousos, 2022). Salivary alpha-amylase, a digestive enzyme has been found to have higher rates of secretion under stress conditions, and is used as a marker for the ANS (Feneberg & Nater, 2020). Similar to cortisol, salivary alpha amylase shows a distinct awakening pattern, which is also used as a stress marker (Agorastos & Chrousos, 2022; Feneberg & Nater, 2020).

Not only are stress responses associated with changes of the HPA-axis and the ANS, they are also associated with changes in immune function (Agorastos & Chrousos, 2022; Feneberg & Nater, 2020; Kemeny, 2003) and cognition (Gerber & Fuchs, 2020, p. 27; Sandi, 2013; Shields et al., 2016).

Stress responses are not only characterized by physiological, immunological and cognitive changes,– we also "feel stressed" (Feneberg & Nater, 2020). Stress is associated with negative affect, including emotions such as anger, rage, anxiety, and frustration (Fuchs & Gerber, 2018, p. 23; Pulopulos et al., 2020). Other characteristic reactions during stress are feelings of tension, depressed mood and reduced motivation (Pulopulos et al., 2020). These affective changes associated with stress are not always accompanied by physiological changes in laboratory stress tasks (Ali et al., 2017; Pulopulos et al., 2020, p. 8). On a behavioral level, individuals engage in different coping attempts (Carver, 2011; Lazarus & Folkman, 1984; Smith & Kirby, 2011), and show different social responses (Taylor & Master, 2011).

Allostatic load – Chronic Stress

The ways that stress can manifest itself in our bodies, brains, and minds has been discussed above. Those descriptions have been made with the assumption of a one-time, acute, stressful event – an exam, a bear attack, a quarrel with a good friend, a marathon. How does long-term stress differ from acute stress?

The stress response occurs when our ability to maintain a balanced internal environment (homeostasis) is strained. Adapting to change leads itself to a changed internal state, called allostasis (Chrousos, 2009; McEwen, 1998). Maintaining allostasis takes a toll on the body, in such way that chronic stress (intense, repeated and prolonged stress responses) leads to *allostatic load*, i.e. "wear and tear on the body and brain resulting from chronic overactivity or inactivity of physiological systems" (McEwen, 1998, p.37).

Chronic stress is associated with worse physical and mental health, including chronic fatigue, inflammation and pain (Agorastos & Chrousos, 2022; Carver, 2011; McEwen, 1998), hypertension (Carver, 2011), depression and increased stress reactivity (Gutman & Nemeroff, 2011).

Differences in stress responses

Chronic stress is associated with adverse mental and physical health outcomes, and repeated and intense stressors are such as daily hassles or the death of a loved one are familiar occurrences in human life. Yet not everybody reacts the same way to the same stressor. The same individual might even react differently to two instances of the same stressor or on different days. For example, two days might be different in whether one anticipates it to be stressful, or in how much physical activity one has engaged in. Both environment factors and person-related factors play role the stress reactivity of a person; I will discuss these in more detail below.

One obvious explanation for differences in stress responses is that differences relating to the stressor or environment. Novel, uncontrollable situations that involve the ego are particularly associated with a strong HPA response, as can be observed with experiments involving the Trier Social Stress Test (TSST) (Feneberg & Nater, 2020). The TSST is a laboratory stress paradigm

that includes social evaluation and a mental arithmetic task. It has garnered great popularity in stress research because such psychosocial stressors consistently elicit strong HPA axis responses. The degrees of ambiguity and uncertainty are thought to influence the stress response and subsequent coping behaviors (Lazarus & Folkman, 1984). Unexpected situations in particular disallow anticipatory stress and coping processes.

Besides environment-related differences, person-related factors influence how individuals react. Personal beliefs and commitments as well as personality influence how relevant and important a given situation is to us (Lazarus & Folkman, 1984).

A common term for person-related factors that decrease stress reactivity is resilience. Stress resilience can be thought of as an "anti-stress-factor". Higher resilience has been associated with lower perceived stress as well as lower scores on anxiety and depression measures (García-León et al., 2019). It can be described in several ways, but most definitions include some similarities: the presence of adverse circumstances, a recovery from those adverse circumstances, and fewer adverse outcomes compared to someone less resilient (Tugade, 2012; Zautra & Reich, 2012). Windle (2011) summarizes different definitions of resilience:

> Resilience is the process of effectively negotiating, adapting to, or managing significant sources of stress or trauma. Assets and resources within the individual, their life and environment facilitate this capacity for adaptation and "bouncing back" in the face of adversity. (Windle, 2011, p. 163)

Thus, anything that has the capacity to either reduce the occurrence of stress, or to reduce stress reactivity and recovery, can be seen as part of resilience. This description closely relates to Lazarus and Folkman's description of resources as something a person can draw upon to deal with subjective stress (Lazarus & Folkman, 1984). Psychological, social, environmental, and biological resources all facilitate this capacity. They can contribute to general resilience, or to resilience to a specific stressor (Roskies, 1991; Windle, 2011). Examples of such resources include emotional regulation, positive emotions and self-esteem (Liu et al., 2018; McEwen, 1998; Tugade, 2012; Zautra & Reich, 2012), social support (Kiecolt-Glaser et al., 2020; Taylor & Master, 2011; Uchino & Birmingham, 2011), and an absence of depression and early-life adversity (Gutman & Nemeroff, 2011).

Anticipatory stress (in daily life)

Differences in stress responses can be explained by resilience, but I also mentioned earlier how stress responses may be different depending on how stressful the day is expected to be. In the following section, I want to consider whether an individual expects the day to be stressful in the first place impacts stress responses. Theoretically, stress measures at the end of the day should be dependent on whether one anticipates a stressful day or not. Empirically, there seems to be an association between anticipatory stress and experienced stress, though it is dependent on how well anticipating the stressor aids in preparing for it, and how resilient the individual is. The following section defines anticipatory stress and describes findings on anticipating a stressful event and how it relates to experiences the anticipated event.

It is intuitive that an oral exam leads to a stress response, but what about *anticipating* the exam? Stress, by definition, has an anticipatory component, as the stress response *prepares* us to adequately deal with a stressor. Conversely, unexpected stressors lead to greater stress responses, as anticipating a stressor allows us to avoid or manage a potentially stressful situation (Lazarus & Folkman, 1984; Stefano et al., 2008). Anticipation may be focused on the future but manifests itself in the present; the stressors that we may anticipate stressors lie in the future, but we become worried and anxious now (Block et al., 2020; McEwen, 1998).

It should be noted that the terminology is not consistent. Some studies use "anticipatory stress", while others use "anticipated stress". Conceptually, these two are not the same. Anticipated stress evokes the *stressor or the stress response in the future,* which is being anticipated in the present. Anticipatory stress evokes the *stress response in the present*, which is evoked by the anticipated stress. Anticipated stress thus can be viewed as a *stressor* in and of itself, which is also what empirical evidence suggests. For clarity's sake, when examining the stress response evoked by anticipating a future stressor or stress response, "anticipatory stress" (AS) will be used.

Empirical evidence for AS can be gleaned from experimental studies such as that from Waugh and colleagues (Waugh et al., 2010). They examined two groups, one anticipating a speech without giving it, and one both anticipating *and* giving the speech. The authors found that

even anticipating a speech without giving it elicits affective and cardiovascular responses. Still, the anticipation group recovered better from negative affect compared to the group that anticipated and gave a speech. The authors suggest that there is a difference in how one recovers from anticipation vs. the stressor itself, with unclear mechanisms. In a similar experiment (Feldman et al., 2004), participants either prepared to give a speech in front of people, or prepared to read aloud in a room alone. The group that experienced AS (preparing for a speech) showed a greater cardiovascular response, threat appraisal, and negative affect. The cardiovascular response was partially accounted for by changes in psychological measures. Another study using the TSST found cortisol measures to be significantly associated with a stress assessment before the stressor took place, but found no significant association for a retrospective assessment (Gaab et al., 2005). In a study using a modified version of the TSST (Pulopulos et al., 2020), participants were split into two groups. Participants were given bogus feedback to have either positive or negative expectancy about the stress task, people with positive expectancy anticipated the stress task as less threatening and perceived that they were more able to deal with it. It was found that the negative expectancy group showed higher AS measures, and that negative expectancy group showed stronger associations between the AS and the magnitude of the HPA axis and psychological stress response, compared to the positive expectancy group. The authors suggest that adaptive anticipatory coping such as reappraisal (as opposed to maladaptive coping such as catastrophizing) serves as a moderator of the relationship between AS and cortisol reactivity and might explain why participants in the negative expectancy group differed from each other. In a review on athletes specifically (van Paridon et al., 2017), included studies measured cortisol levels before a competition as well as on a non-competition day. The review found that athletes showed significantly higher cortisol levels on a day when they anticipated a competition, compared to a non-competition day. Interestingly, female athletes did not show higher cortisol levels, which was attributed to males generally having higher cortisol responses. Those competing in international competitions did not show higher cortisol levels either; the authors suggest that international athletes tend to be more experienced, and as experience with competition increases, AS is reduced.

Besides experimental studies, there have been several studies examining AS in daily life, using ecological momentary assessments. One study examining 284 participants found AS in the evening to be associated with worse sleep quality and higher negative affect the next day (Block

et al., 2020). These associations were not explained by differences in trait insomnia or personality trait openness, which were assumed to influence sleep quality as well. Additionally, the authors suggest that worse sleep quality could lead to a decreased ability to deal with stressors the next day. In another EMA study with a sample of 42 participants (Kramer et al., 2019, p. 38), AS measured the night before was associated with a steeper cortisol awakening response. In a two-week study of 112 working adults (Casper & Sonnentag, 2020), work-related worry (a maladaptive anticipatory coping effort) in the evening was shown to be associated with next-morning exhaustion. On days where worry was high, workload anticipation was associated with greater exhaustion. The authors theorize that negative thoughts and repeated worry depleted the participants' energy and that high levels of worry increased the effect of high expected workload. In a different study of 110 undergraduate students (Wang et al., 2021), underpredicting stress led to higher health complaints and more negative affect. More negative affect in the morning and bad sleep quality in turn led to more AS. Powell and Schlotz (2012) conducted a two-day EMA study in which they assessed cortisol awakening responses and asked participants how stressful they anticipated the upcoming day to be in the morning. Then, throughout the day, PS and negative affect were assessed at six semi-random timepoints between 10AM and 20:30PM. They found that AS in the morning was neither associated with PS throughout the day, nor with negative affect throughout the day. Additionally, the cortisol awakening response was not associated with same day AS. This study is therefore not in line with other EMA studies; however, this could be due to the comparatively low number of participants (23) and only two days being assessed.

To summarize, several EMA studies showed AS to be associated with stress during the same or during the next day. One study that might show how AS and PS might interact was done by Hyun and colleagues (2019). In a two-week EMA, AS in the morning was associated with worse working memory performance during the day. This was the case even when controlling for stress levels that day. The authors suggest that AS has consequences independent of PS, and that AS and PS act *additively*. However, the additive effect seem to be dependent on how resilient a person is and on how well the AS leads to effective coping efforts, as described in a study by Scott and colleagues (2019). In a 14-day EMA, participants completed five surveys a day in semi-random intervals, with about 2,5 hours between prompts. During each prompt, they reported their negative affect levels, if a stressful event had happened since the last prompt, and

if they expected a stressful event to happen in the next 2,5 hours. They found that participants could more accurately predict that no stressor would occur than they could predict that one would occur. The authors propose that individuals are likely inflating the chance for negative events and are trying to avoid or control the stressor beforehand, which means that the likelihood that a stressor *would* occur was overpredicted (thanks to coping efforts following such a prediction, a stressor did not occur in the end, making the earlier predictions less accurate). Additionally, anticipating a stressor was associated with negative affect, and negative affect was raised after a forecast even when no stressor was reported to have happened. Anticipating stressors thus led to an increase in negative affect independent of reported stressors. In fact, negative affect was higher for reported stressors in cases where a stressor had been forecast, than when no stressor had been forecast. These results suggest that AS responses and current stress responses can act *additively*. However, the authors note that no stressor would be reported when the participant had successfully coped or avoided the forecasted stressor, and that it is much more likely that the reported stressors were those that were not effectively dealt with after a forecast had been made. It is thus likely that the additive effect occurs more often when anticipation of a stressor does not lead to effective coping. The idea that AS only adds onto PS when it does not lead to effective coping is supported by a study by Lee and colleagues (2020). They developed an app that allowed participants to enter anticipated stressful events, to plan interventions, and to evaluate stress levels after said intervention. Participants were able to enter stressful events on a calendar and rate the AS level on a five-point scale. They were then able to plan an intervention and set a reminder for when it should take place. For evaluation, they reported their stress levels every evening. On days where an event was entered, they reported whether the event had happened and the experienced stress level, and if they had completed the corresponding intervention. Crucially, participants were split into groups, with one group being able to plan and evaluate interventions, while this function was blocked for the other group. The app was deployed over 30 days. In about half of the cases, AS levels and reported stress levels were the same. Participants who neither planned nor executed an intervention reported higher reported stress levels than expected. Planning an intervention lowered an event's reported stress level, while genuinely executing the intervention led to a larger drop. The authors note that sometimes, anticipation may not actually help with preparation, but may lead to more stress and hinder preparations. In addition, unexpected events, which are impossible to prepare for, may

cause greater stress. The authors conclude that AS may help or hinder anticipatory coping attempts, depending on how well the anticipation prepared a participant for the stressor.

To summarize, anticipatory stress (AS) seems to be associated with subsequent stress measures and anticipating a stressor leads to AS that may act additively to stress response that occur later. Importantly, this does not seem to happen in all cases. In situations where anticipating the stressor led to preparing well for said stressor, AS was associated with *less* perceived stress (PS) at a later time point. Thus, the direction and strength of the relationship between AS and PS is dependent on whether AS leads to functional and effective preparations. Interestingly, Scott and colleagues (2019) found that participants tend to overpredict stress, and Wang and colleagues (2021) report that overpredictions were less likely to occur for individuals who are high in trait resilience. They suggest that individuals high in resilience are less likely to make stressful appraisals and are more likely to believe that they have adequate resources, thus making it less likely that they expect a day to be stressful. One factor that is associated with greater resilience, and which is of particular interest to this thesis, is physical activity and exercise (Wang et al., 2021). The following section will first discuss definitions and differences between related terms before discussing findings relating to health and stress.

Physical activity

Physical activity (PA) is a broad construct and includes all bodily movements that raise energy expenditure above the maintenance level (Fuchs & Gerber, 2018, p. 5). Sports, a related term, has grown out of cultural and historic circumstances and typically refers to physical activity with the purpose of competition, fun, or performance. Physical exercise is a related term that refers to a structured physical activity that is done for the sake of training one's body or to increase physical fitness (exercise will be used synonymously with physical exercise in this study, and not refer to exercise for one's brain or mental sports). Physical fitness is a set of health related traits and or skills, and physical exercise levels predict fitness (Abu-Omar & Rütten, 2006; Caspersen et al., 1985). PA is thus the broadest term and includes movements that are done at work, during leisure time, as well as during one's commute. Usually, these activities are done with energy conservation in mind. However, some individuals might design their activities in a way as to "burn calories", for example when vacuuming the floor is done "as exercise".

Difficulties in examining current literature also arise due to the use of "physical activity" in cases when "exercise" would be more accurate. This is so much so the case that most mentions of "physical activity" are indeed referring to exercise, leading to the circumstance that there is little research examining the more abstract, *general physical activity*. Thus, it is unclear if most of the findings in the literature are only applicable to exercise or also other physical activities. In the context of the discussed literature, I will still use the terms exercise and PA as introduced above. For example, if a study used the term PA, but described exercise as defined here, I will use the term exercise in discussing the findings.

As mentioned, physical activity may be engaged in in different contexts, e.g., leisure, work, and commute. Physical activity is also usually divided by intensity. In literature, it is usually divided into light, moderate, and vigorous intensity, mostly following the division that are outlined in the most recent WHO guidelines on physical activity and sedentary behavior, which draw on previous empirical evidence on physical activity, exercise, and sedentary activity (World Health Organization, 2020). Light (intensity) physical activities (LPA) usually include activities that do not substantially increase heart rate or breathing, such as walking. In fact, most of the time, LPA is used synonymously with walking. Moderate (intensity) physical activities (MPA) are usually rated 5-6 on a 10-point subjective intensity scale (World Health Organization, 2020), and lead to noticeably increased heart rate and breathing, but still allow for talking, such as light jogging or swimming. Vigorous (intensity) physical activity (VPA) is usually rated as above 6 and leads to high increases in heart rate and breathing. One sweats profusely and cannot speak fluently. Examples include sprinting, lifting weights or moving heavy furniture. In the literature, MPA and VPA are sometimes combined and referred to as moderate-to-vigorous (intensity) physical activity (MVPA), which is sometimes used synonymously with exercise. LPA should not be confused with leisure-time physical activity (LTPA), which sometimes includes commutes (Dahlstrand et al., 2021), other times does not (Stults-Kolehmainen & Sinha, 2014), and yet other times is only defined as activities that are not mandatory (Kim & McKenzie, 2014). Lastly, while not physical activity per se, sedentary behavior (SED) is sometimes included to assess the effects of physical inactivity.

Following these definitions, representative survey results from 2005 indicate that 37% of the German population did not engage in any daily exercise or sports[2]. They rank second in the EU regarding the sum of all weekly physical activity, while Austria ranks in the middle

[2] The German „Sport" here can mean both exercise and sports

compared to other EU members. In contrast, Austria ranks high regarding sports activity (Rütten et al., 2005, p. 1). According to a representative survey by Statistik Austria (15.461 respondents) (STATISTIK AUSTRIA, 2020), 23% of Austria's population fulfilled the WHO recommendations for physical activity during leisure time in 2019, with younger age and male sex being associated with more physical activity. About 45% of the population work in mostly sedentary occupations and half of the population spent at least ten minutes of their commute on foot, while 4% used a bike. Men are three times more likely to engage in vigorous physical activity at work, while women engage in more moderate physical activity.

Physical activity and health

Physical activity has been found to have a positive impact on physical health. The effects are dependent on the context in which the physical activity is engaged in (Abu-Omar & Rütten, 2006; World Health Organization, 2020). The effects of physical activity on health follow an inverse U-Shape, indicating that even a low amount of physical activity can have positive effects, with the most notable effects being associated with a medium amount of PA, while extreme PA is associated with adverse health outcomes. (World Health Organization, 2020, p. 44). Sedentary behavior increased the risks for various physical diseases and all-cause mortality, i.e. the risk of death due to any cause. A dose-response relationship was found here as well, meaning that more sitting led to worse health outcomes. It was found that moderate to vigorous physical activity could attenuate the detrimental effects of sitting on health. It is unclear whether lower intensity physical activity has the same effect and whether this varies by type or context of physical activity (World Health Organization, 2020).

Both physical activity and exercise have been associated with improved mental health. Physical activity reduces the odds for clinical anxiety and depression (Biddle & Asare, 2011; World Health Organization, 2020), and exercise showed comparable effects to pharmacological treatment for clinical depression (Fox, 1999; K.-H. Schulz et al., 2012). PA was associated with fewer psychosomatic, depressive and anxiety symptoms and improved wellbeing (Dahlstrand et al., 2021; Kim & McKenzie, 2014).

Physical activity and stress (in daily life)

One mechanism that might explain the positive effects of physical activity on health might be its impact on stress. The following section will first discuss observational studies, followed by experimental evidence and reviews. These findings, however, are based on cross-sectional and experimental evidence. Since the goal of this thesis is to examine participants in their daily lives, I will close the discussion of PA and stress with EMA evidence.

Observational studies have found a link between PA and stress indices. PA was associated with less perceived stress (PS) in an adolescent sample (Dahlstrand et al., 2021). In college samples, exercise (Moeller et al., 2020), and PA (Nguyen-Michel et al., 2006) were associated with less PS, anxiety, depression, and college related worries. Preservice teachers, i.e. student teachers, who had more lifetime sports and exercise experience showed a higher level of stress resilience. Teachers who were currently exercising regularly showed a slower decline of positive affect in stress situations (Ozkara et al., 2016). In working adult samples, LTPA was associated with lower stress levels and fewer burnout symptoms (Gerber et al., 2018; Gerber et al., 2020; Isoard-Gautheur et al., 2019). Commute-related PA was found to improve stress resilience (Dėdelė et al., 2019). Regarding the general population, exercise was found to buffer the adverse effects of stress on health (Berger, 1994; Gerber & Pühse, 2009; Schnohr et al., 2005), and LTPA (Schnohr et al., 2005) as well as sports (Wijndaele et al., 2007) were associated with less PS and life dissatisfaction.

Experimental evidence on VPA points to it leading to reduced PS, depression and anxiety (Klaperski & Fuchs, 2021; Norris et al., 1992). This seemingly contradicts the findings presented in the WHO guidelines, which showed adverse health outcomes for extreme PA. However, extreme PA refers to the activity of professional athletes, and not regular men[3] undergoing an exercise training program, which is what was analyzed in the studies mentioned above. As for LPA, in a rather interesting experiment (Lambiase et al., 2010), children completed either a 20-minute walking task or a sedentary control task, as well as a 20-minute recovery period where cardiovascular measures returned to baseline, before being exposed to a laboratory cognitive stress task. The walking task was comprised of twenty minutes of walking on a treadmill, while watching a slideshow of the school neighborhood, the task imitated a commute to school by foot and. The control group spent those twenty minutes reading magazines and watching the

[3] The research referred to here exclusively examined male participants.

slideshow while sitting. The walking task group showed less cardiovascular reactivity and PS, which suggests that physical activity in the form of an active commute might dampen stress reactivity. However, the simulated school commute results might not be applicable to real commutes. The laboratory commute was simulated on a treadmill, with pictures of the streets changing and the school coming closer being projected in front of the children. However, other studies, using the TSST-paradigm, also found exercise to be associated with decreased stress reactivity, namely lower cortisol and cardiovascular reactivity, as well as decreased psychological stress reactivity such as mood improvements and smaller increases in anxiety (Gerber & Pühse, 2009; Mücke et al., 2018; Puterman et al., 2011; Wunsch et al., 2019). Men who completed a physical activity task beforehand showed reduced cortisol secretion when faced with a psychosocial stressor (Wood et al., 2018). Differences in stress reactivity in response to the TSST were also found between physically fit men and physically unfit men, with fit men showing a blunted physiological and psychological stress reactivity (Mücke et al., 2018; Rimmele et al., 2007; Strahler et al., 2016).

PA does seem to decrease stress reactivity and these stress-buffering effects seem to increase with the intensity level of PA, though it is unclear if a threshold must be reached before decreased stress reactivity takes effect. Some authors suggest that LPA is insufficient to show any effects and that a certain threshold must be reached, while others point out that LPA shows smaller, but still present effects (Norris et al., 1992; Reiner et al., 2013; Schnohr et al., 2005).

Having just discussed the stress-buffering effects of PA, I want to continue with proposed mechanisms. One way that physical activity reduces PS is by being used as a coping strategy. According to representative surveys, 40% of adult Canadians used physical activity as coping with stress in 2014 (36,984 respondents) (Cairney et al., 2014), as did 72% of Germans in 2009 (1,014 respondents) (TK & F.A.Z-Institut, 2009). Exercise as coping was associated with being female, higher socioeconomic status, sedentary work conditions and other health behaviors such as smoking or dietary choices. Not only do individuals use PA as coping, evidence also suggests that it is effective in doing so. Exercise has been shown to be an effective management tool, leading to lower stress scores (Garber, 2017), and was found to buffer negative effects of stress on health (Gerber & Pühse, 2009). As a mechanism, Sharon-David and Tenenbaum (2017) propose that exercise may act as a distraction from stressors and thus offer a short reprieve for the mind. Others propose different reasons, such as mindfulness, mind-body connection, positive

affect, locus of control, and association with other positive coping strategies (Dahlstrand et al., 2021; Kim & McKenzie, 2014). Cairney and colleagues (2014) propose that the effectiveness of exercise as coping is mediated by the individuals' intrinsic motivation to do exercise.

Physical activity as a coping method seems to be effective in directly dealing with stressors, but it may show stress-buffering effects even if it is not used as a direct coping method. PA has been proposed to influence stress in other, more indirect ways as well. The Cross-Stressor-Adaptation-Hypothesis (Sothmann et al., 1996) posits that PA of sufficient intensity acts as a stressor and thus leads to changes in biological stress mechanisms. Importantly, this leads to the individuals being better prepared not only when the stressor is physical in nature, but also when the stressor is a psychosocial or cognitive one (Fuchs & Gerber, 2018; Gerber & Fuchs, 2020; Sothmann et al., 1996). There is some evidence for this, as exercise measures are associated with reduced measures of both ANS and HPA responses to psychosocial stressors (Aldana et al., 1996; Gerber & Fuchs, 2020; Silverman & Deuster, 2014). Besides physiological adaptations, exercise is proposed to improve mindfulness (Goldstein et al., 2020), self-efficacy, behavioral planning, sense of control, and self-schemata (Edenfield & Blumenthal, 2011; Long & Flood, 1993; Sharon-David & Tenenbaum, 2017; Wijndaele et al., 2007). These may help individuals better able to regulate their emotions. They might still experience psychological stress but may be able to manage it before it translates into physiological stress; and these individuals may have improved recovery from ongoing stress responses (Edenfield & Blumenthal, 2011; Gerber & Fuchs, 2020). An elevation in mood and increased positive affect is another possible mechanism for the stress-buffering effects of PA (Berger, 1994; Kim & McKenzie, 2014). The described physiological and psychological resources, such as physiological adaptations or self-efficacy, may also allow a person to appraise a situation as harmless, or assist them in coping efforts (Fuchs & Gerber, 2018; Gerber & Fuchs, 2020).

PA seems to have a stress-buffering effect, however, the evidence provided so far stems from experimental and cross-sectional studies. To allow for assertions about whether PA buffers stress in our *day-to-day* lives, I will present evidence from ecological momentary assessment (EMA) studies. This study design examines participants in their daily lives, usually via smartphone apps. It is thus particularly suited to research how stress appears "in real life". In a study entailing 13 year-old students, participants were asked to complete a baseline survey measuring PS, and were then asked to wear an accelerometer during waking hours for a week

(Dahlstrand et al., 2021). The authors found that as daily PA increased, PS measured at baseline decreased. This association held true for all levels of physical activity, meaning light, moderate, and vigorous physical activity. The results were not significant for school-time PA, but were significant for leisure time PA, which included commutes. Other studies measured physical activity and stress measures multiple times a day. For example, Schwerdtfeger and colleagues (2008) found episodes of physical activity (measured via accelerometer) to be associated with higher subsequent positive affect when compared to measurements before the physical activity episode, but with no differences in negative affect. Another study (Kanning & Schlicht, 2010) asked participants to complete a set of questions after specific episodes during their daily routine. Episodes were defined as occurrences with a definite start and end, and were self-selected by the participants. The authors then categorized the episodes as physically active or physically inactive. They found that participants' mood was more positive in valence, calmer, and more energetic after an episode of physical activity. In a study over eight days (Schultchen et al., 2019), participants were prompted six times a day, with the first prompt at 9AM and additional prompts following every 2,5 hours, ending at 9:30PM. Prompts included questions about affect and PS, and minutes of VPA. VPA was associated with less subsequent stress and negative affect and more positive affect the following prompt. Vice versa, worse stress and affect measures led to a decrease VPA measures the following prompt. The authors theorize that [vigorous] PA is effortful and might thus be ignored in times of stress due to time constraints, exhaustion, or low motivation. Similar to Cairney and colleagues (2014), intrinsic motivation and enjoyment were proposed as mechanism for the positive effects of physical activity (Schultchen et al., 2019).

Not only can physical activity lead to less stress, but stress can lead to less physical activity. A 2014 review (Stults-Kolehmainen & Sinha, 2014) found that stress generally has a negative influence on exercise, particularly for individuals who do not regularly exercise. Individuals that do regularly exercise may differ in how important regular exercise is to them. Exercise may hence be dropped by some individuals in times where there are other situations demand one's resources, or when other activities provide more stress relief. Exercise might also be associated with negative feelings, acting as a psychological stressor in and of itself. This may be especially the case for clinically depressed individuals, who tend to show higher chronic stress levels, who may be even less motivated to engage in exercise.

Research Questions and Hypotheses

In summary, both physical activity (PA) and anticipatory stress (AS) may show stress-buffering effects. Both PA and AS might have an influence on levels of perceived stress (PS) in day-to-day life, which is what this study aims to examine. To do this, I will first examine the relationship between PA and stress, before asking if PA moderates the relationship between AS and PS.

For the relationship between PA and PS, a dose-response relationship can be assumed, though most empirical evidence was found for moderate-to-vigorous PA (MVPA). Together with the fact that most studies only measured exercise but referred to it as physical activity, this makes it difficult to gather which effects may apply only to MVPA or exercise, and which apply to PA in general. The ecological validity of available experimental and cross-sectional studies can be criticized, and studies that made use of an EMA design were done on adolescents, only assessed VPA, or only differentiated between periods with PA and without PA.

The gaps in the literature have led to the aim of examining individuals in their day to day lives and to assess different levels of physical activity, and to the formulation of the following research question:

Does daily physical activity affect daily perceived stress?

This question aims to contribute findings not only on exercise, but on PA in general, as the effect of LPA is currently unclear. Following hypotheses have been generated from this question:

H_1: Greater daily physical activity is associated with less daily perceived stress.

This hypothesis is formulated as directional, since most of the evidence points to PA being associated with better psychological stress indices.

H_2: a) Moderate-to-vigorous physical activity is associated with perceived stress; and b) light physical activity is not associated with perceived stress.

Although some authors suggest that even LPA alone shows may influence stress reactivity, many others argue that only more intense physical activity, aka exercise, shows stress-buffering effects (e.g., Edenfield & Blumenthal, 2011; Norris et al., 1992; Schnohr et al., 2005). Thus, this hypothesis is formulated as MVPA being able to explain changes in PS, but not LPA. I expect PA in general is to be associated with PS and expect that this association is explained through MVPA.

PA may show its effects through influencing the relationship between AS and PS. AS leads to physiological, cognitive, and psychological stress responses. Interestingly, AS and PS add up (Casper & Sonnentag, 2020; Hyun et al., 2019; Pulopulos et al., 2020; Scott et al., 2019). This seems to be the case when AS does not lead to successful anticipatory coping. The inability to avoid or manage a future stressor effectively can result in one prolonged, or two separate stress responses (one in anticipation of the event and one in response to the event). Resilience and stress reactivity may influence the need for and effect of anticipatory stress (Wang et al., 2021). One factor influencing resilience and stress reactivity is physical activity (e.g. Dahlstrand et al., 2021; Edenfield & Blumenthal, 2011; Norris et al., 1992; Ozkara et al., 2016. Thus, one possible way by which physical activity buffers stress is by affecting AS. To my knowledge, no other study until now has examined how PA might influence the relationship between AS and PS. This leads to following research question:

Does physical activity moderate the relationship between anticipatory stress and experienced stress?

Two hypotheses have been generated from this as well:

H_3: Anticipatory stress is associated with perceived stress later in the day.

AS and PS later in the day sometimes add up. This seems to not be the case when the individual successfully avoids or manages the anticipated stressor. As it is not clear if participants manage to avoid or cope with anticipated stressors, this hypothesis is non-directional. If participant engages in successful adaptive coping, I expect a negative relationship between AS and PS. If participants are not resilient or cannot adaptively cope, I expect a positive relationship between AS and PS.

H_4: The relationship between anticipatory stress and perceived stress later in the day is moderated by physical activity.

Physical activity is assumed to be effective in aiding an individual to avoid or manage a stressor. Thus, physical activity should moderate how tightly and in which direction AS is associated with PS.

Methods

Study Design

Ecological Momentary Assessment

As this thesis is focused on examining potential stress-buffering effects as they occur in participant's daily lives, an approach taking daily measurements in a participant's daily life is most suited. This study thus is based on an ecological momentary assessment approach. Even though there are theoretical distinctions, the terms EMA, experience sampling methodology, and ambulatory assessments are often used interchangeably (Trull & Ebner-Priemer, 2009). EMA can be used to refer to different kinds of "daily life sampling approaches". This current study will use only the term EMA to refer to this kind of study design.

Retrospective measurements can invite systemic bias into the data, due to recall being distorted and biased by heuristics. With EMA, a study design which measures changes as they unfold over the course of the daily life of a participant, it is possible to examine daily stress and

physical activity more directly. Other methods are removed in time (retrospection) or context (laboratory settings), and thus pose a more "distal" measurement, whereas EMA offers more "proximal" measures.

This study's approach uses two prompts a day, one in the morning, and one in the evening, to assess AS, PA, and PS.

Study Procedure

This master's thesis is part of a larger project examining the Amylase-Awakening response and factors that impose possible influences on it. The aim of the larger project is 90 completed participants. Due to time constraints, this thesis comprises individuals who had completed participation by the time of writing, resulting in a sample of seven participants.

Recruitment for the participants of the study was done via posters hung around the university and via posts on Facebook and Instagram, which included an image file of the recruitment poster, as well as a written text of the information contained within. The poster targeted men and women and included a short description of the study, the duration, and compensation, as well as a selection of inclusion criteria (see Appendix 1).

Interested individuals underwent a phone screening to determine their eligibility for the study and were included based on following criteria: 18-35 years old, BMI in the range of 18,5 to 25, working German levels, no pregnancy, breastfeeding, or hormonal contraception. No current or history of physical or mental illnesses or disorders, no recreational drug use, or use of medications (such as Isotretionin) that have been known to impact regulation of the biological stress system.

Eligible participants were invited for an in-person appointment at the department of psychology of the University of Vienna. Participants were informed of the study goals and procedure, and written consent was obtained. Afterwards, they completed an online questionnaire, which included questions about PA the past seven days (IPAQ), which was included as a covariate. In addition, study materials (saliva sampling tubes, study phone) were provided for the EMA component of the study.

Participants collected data every day for 30 days, for men, and for the duration of one menstrual cycle for women. Women began data collection on day 2 of their cycle, one day after menstruation started, until at least day 3 of the next cycle.

Each day, participants completed two reports on their phone using the Movisens app (movisensXS, Version 1.5.23 (movisens GmbH, Karlsruhe, Germany)), one in the morning, and one in the evening before going to bed. The morning questions gathered information about any stressors they might anticipate in the day ahead, among other measures that are not pertinent to this study. Evening questions included self-reports on daily levels of physical activity (IPAQ), and perceived stress (PS) - stress experienced during the day.

After the daily data collection period, participants came in for a second in-person appointment. Study materials were returned, and another online questionnaire was completed, including questions about PA the past seven days (IPAQ), chronic stress (SSCS), and trait depression (BDI), which were included in the study as covariates.

Measurements

Anticipatory Stress

Anticipatory stress was assessed by asking participants in the morning, if they expected any stressful or challenging tasks that upcoming day. The prompt read: “Werden für den heutigen Tag besonders herausfordernde oder stressvolle Aufgaben auf Sie zukommen?”, a direct translation would read: “Will there be any particularly challenging or stressful tasks coming up for you today?”.

Perceived stress

Perceived stress was measured via the German version of the Perceived Stress Scale with 4 items (PSS-4; Cohen et al., 1983). The PSS-4 was validated on an English sample (Warttig et al., 2013); validation on a German sample was done using the 10 item version (Klein et al., 2016). The original version of the PSS-4 assesses perceived stress over the past month, e.g.

"How many times during the last month did you have the feeling that tasks or problems have piled up so much that you could not handle them?". Modifying the PSS for an EMA study with daily measurements yielded similar results to the non-modified version (Schultchen et al., 2019, p. 319). For the present study, items have been modified to assess stress during the past *day*, e.g. "How many times *today* did you have the feeling that tasks or problems have piled up so much that you could not handle them?".

Physical activity

The original short form of the International Physical Activity Questionnaire (IPAQ-SF) assesses PA during the last seven days. One concern about the seven-day version was that it was not applicable to shorter recall times. A version assessing PA during the past day has been validated (Kurth & Klenosky, 2021). The IPAQ is an open access questionnaire and has been shown to have similar psychometric properties to other self-report measures of PA (Craig et al., 2003). The IPAQ assesses walking (LPA), moderate (e.g. gardening or light jogging) (MPA), and vigorous physical activity (e.g. sprinting or lifting heavy weights) separately (VPA), and also assesses sedentary activity. Each item includes examples for each activity level, and asks whether, and how many minutes of said activity have been done that day. PA in general was the sum of LPA, MPA, and VPA. Additionally, moderate-to-vigorous PA was calculated as the sum of MPA and VPA.

Covariates

Possible covariates were assessed in trait PA, trait depression, and chronic stress measures. Person-level differences in PA could in part explain associations between daily PA and daily PS. Trait PA was calculated using the average of IPAQ scores of the first and second appointments. Person-level differences in chronic stress could be associated with daily differences in PS (higher daily stresses presumably accumulate to higher chronic stress). Furthermore, chronic stress is associated with physical inactivity (Stults-Kolehmainen & Sinha, 2014) and was assessed using the Screening Scale for Chronic Stress (Screening Skala für chronischen Stress; P. Schulz et al., 2004). Trait depression was found to be associated with less

PA and more chronic stress (Gutman & Nemeroff, 2011; Stults-Kolehmainen & Sinha, 2014) and was assessed using the Beck Depression Inventory (Kühner et al., 2007).

Analysis

Due to the EMA approach and the resulting nested data structure present in this study, analysis was done using multilevel modeling. I further found MLM to be appropriate, because it is able to accommodate missing data better than conventional regression analyses (Field, 2018; Heck et al., 2014). A set of multilevel models was computed using IBM SPSS (version 29), with maximum likelihood estimation, significance levels were set at $p \leq 0{,}05$. PA, LPA, and MVPA were person mean centered. Person mean centering is recommended when interactions at the within-person level are of interest, as is the case in this study (Field, 2018). Models were computed stepwise, starting with a null model containing no predictors and the intercept for subjects as a random effect to check for clustering, next, a model that included all covariates (trait PA, trait depression, chronic stress) was computed, this was followed by models that entered one additional predictor per model. To analyze the effects of PA and AS on PS, I entered PA (continuous scaled), AS (0 = no stress anticipated), as well as their interaction term. To analyze if effects were dependent on PA level, MVPA and LPA and their respective interaction terms with AS were added in subsequent models.

Results

In total, seven individuals completed participation, meaning that they completed the screening, the first appointment, several weeks of data collection, and the last appointment. Thus, data from seven participants were used for analysis. Individuals' daily life data collection lasted from 25 to 35 days. Participants were aged 23-30 years (mean = 24,71; SD = 2,56). Out of seven participants, six were female. On most days, no stress was anticipated (63,7%) (Table 1). An average of about 143 minutes (SD = 147,25) of physical activity were done each day (Table 2), with MVPA making up about a third of the total time spent in PA (mean = 47,07; SD = 85,65).

An initial null model was computed, with only the intercept of subject included as a random effect, to determine if data are clustered and a multilevel model is applicable (outcome: perceived stress). It showed an ICC of ,57 , meaning that about 57% of variance lay within persons. Variance of intercepts at level 2 was not significant, Estimate = 6,01; Wald Z= 1,824; p = ,068. This p-value was halved according to Heck et al. (2014), yielding p= ,034; which suggests significant clustering and supports the use of multilevel models.

Following the null model, I entered the covariates (trait PA, chronic stress, trait depression, see table 3). To test whether PA was associated with PS (H_1), a model with the covariates and PA was run, but no significant effect was found for PA (model 2 in table 4). Next, I added AS into the model to analyze whether it was associated with PS (H_3), which also yielded insignificant results (model 3 in table 4). Next, I added the PA*AS interaction term to test whether PA moderated the relationship between AS and PS (H_4). This model which included covariates, PA, AS, and the interaction term (model 4 in table 4) found no significant effects for either PA, b = -0,004 (SE = 0,003; 95% − CI [-0,01 ; 0,003]), t(163) = -1,15, p = ,25; AS, b = 0,44 (SE = 0,47; 95% − CI [-1,37 ; 0,48]), t(163) = − 0,95 , p = ,35; or PA*AS, b = 0,002 (SE = 0,004; 95% − CI [-0,006 ; 0,009]), t(163) = − 0,42 , p = ,68.

To test whether effects on PS may depend on the intensity of PS (H_2), I split PA into MVPA and LPA and entered these into the model (model 5 and model 6 in table 4, respectively). Since PA did not show a moderating effect on AS→PS(H_4), I wondered if I could find an effect if I split PA by intensity, hence I entered the respective interaction terms of MVPA and LPA with AS into the model as well (model 7 and 8 in table 4, respectively). Similar to the model including the unsplit PA, the final model that included covariates, MVPA, LPA, AS, and interaction terms (model 8 in table 4) found no significant effects for MVPA, b = -0,003 (SE = 0,004; 95% − CI [-0,01 ; 0,005]), t(161) = -0,638 , p = ,52, or AS, b = -0,40 (SE = 0,50; 95% − CI [-1,40 ; 0,59]), t(161) = -0,80 , p = ,43. Neither interaction term (i.e., MVPA*AS and LPA*AS) were found to be significant (see table 4).

Table 1

Frequency of expecting a stressor or challenge that day

	N	%
No	137	63,7%
Yes	47	21,9%
Missing	31	14,4%

Table 2

Descriptive Statistics for continuous variables

	N	Minimum	Maximum	Mean	SD
PA	192	0	705	143,41	147,25
MVPA	192	0	645	47,07	85,65
PS	207	2	14	6,77	3,24
Trait PA	215	57	128	100,53	24,69
Chronic stress	215	2	35	15,41	9,58
Trait depression	215	0	15	5,77	5,71

Note. N = number of valid measurements (number of participants * number of recorded days); SD = Standard Deviation; PA = physical activity per day in minutes; MVPA = moderate to vigorous physical activity per day in minutes; PS = daily perceived stress; Trait PA = Average physical activity over the last seven days in minutes

Table 3

Pearson correlations between covariates and the dependent variable

	Trait PA	Chronic stress	Trait depression	PS
Trait PA	1	,328**	,601**	,001
Chronic stress	,328**	1	,807**	,507**
Trait depression	,601**	,807**	1	,582**
PS	,001	,507**	,582**	1

Note. Trait PA = Average physical activity over the last seven days in minutes; PS = daily perceived stress

** $p \leq .05$ ** $p \leq .01$*

Table 4

Estimates for multilevel models predicting perceived stress (standard error) [95% - confidence interval]

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Intercept	11,80*** (1,29) [8,76 ; 14,86]	11,72*** (1,42) [8,32 ; 15,12]	11,92 *** (1,47) [8,37 ; 15,48]	11,92 *** (1,47) [8,37 ; 15,48]	11,97 *** (1,47) [8,34; 15,51]	11,95 *** (1,47) [8,41; 15,49]	11,96 *** (1,47) [8,43; 15,49]	11,96 *** (1,45) [8,45; 15,46]
PA		-0,002 (0,002) [-0,01;0,001]	-0,002 (0,002) [-0,006 ; 0,001]	-0,003 (0,003) [-0,01 ; 0,003]				
AS			-0,43 (0,47) [-1,35 ; 0,5]	-0,44 (0,47) [-1,37 ; 0,5]	-0,52 (0,48) [-1,46 ; 0,43]	-0,47 (0,48) [-1,42 ; 0,48]	-0,45 (0,49) [-1,41 ; 0,51]	-0,43 (0,49) [-1,39 ; 0,52]
MVPA					-0,003 (0,003) [-0,01 ; 0,002]	-0,003 (0,003) [-0,01 ; 0,002]	-0,002 (0,004) [-0,01 ; 0,01]	-0,002 (0,004) [-0,01 ; 0,01]
LPA						-0,002 (0,002) [-0,01 ; 0,002]	-0,002 (0,002) [-0,01 ; 0,002]	-0,004 (0,004) [-0,01 ; 0,004]
PA*AS				0,001 (0,004) [-0,01 ; 0,01]				
MVPA*AS							-0,002 (0,005) [-0,01 ; 0,01]	-0,001 (0,005) [-0,01 ; 0,01]
LPA*AS								0,003 (0,01) [-0,01 ; 0,01]
Trait PA	-0,08*** (0,01) [-0,11 ; -0,05]	-0,08*** (0,01) [-0,11 ; -0,04]	-0,07** (0,01) [-0,11 ; -0,04]	-0,07** (0,01) [-0,11 ; -0,04]	-0,07** (0,01) [-0,11 ; -0,04]	-0,07** (0,01) [-0,11 ; -0,04]	-0,07** (0,01) [-0,11 ; -0,04]	-0,07** (0,01) [-0,11 ; -0,04]
Chronic Stress	-0,05 (0,04) [-0,16 ; 0,5]	-0,05 (0,05) [-0,17 ; 0,07]	-0,03 (0,05) [-0,16 ; 0,09]	-0,03 (0,05) [-0,16 ; 0,09]	-0,03 (0,05) [-0,16 ; 0,09]	-0,03 (0,05) [-0,16 ; 0,09]	-0,03 (0,05) [-0,16 ; 0,09]	-0,03 (0,05) [-0,16 ; 0,09]
Trait depression	0,59*** (0,1) [0,4 ; 0,79]	0,059*** (0,1) [0,36 ; 0,81]	0,55*** (0,11) [0,31 ; 0,79]	0,55*** (0,11) [0,30 ; 0,79]	0,55*** (0,11) [0,30 ; 0,79]	0,55*** (0,11) [0,30 ; 0,79]	0,55*** (0,11) [0,30 ; 0,79]	0,55*** (0,11) [0,30 ; 0,79]
-2LL	910,68	852,54	760,80	760,70	761,52	760,66	760,57	760,28
AIC	922,68	866,54	776,80	778,70	777,52	778,66	780,57	782,28
BIC	942,67	889,34	801,89	806,93	802,61	806,88	811,93	816,77

Note PA = physical activity; AS = anticipatory stress (0 = no stress expected); MVPA = moderate-to-vigorous PA; LPA = light PA; -2LL = -2 * log likelihood; AIC = Aikaike's information criterion; BIC = Schwarz's Bayesian criterion

* $p \leq 0,05$ ** $p \leq 0,01$ *** $p \leq 0,001$

Discussion

Anticipatory stress

One of this study's aims was to examine a possible moderating effect of PA on the relationship between anticipatory stress (AS) and PS. I tested whether AS in the morning is associated with PS later the same day (H_3), and whether PA moderates the relationship between AS and PS (H_4).

Current results are insignificant, suggesting that AS and PS are independent of each other. However, one would have expected AS and PS to be associated, based on available literature (Casper & Sonnentag, 2020; Hyun et al., 2019; Pulopulos et al., 2020; Scott et al., 2019). Firstly, current results contrast with the notion that AS and PS may in fact act additively. In consequence, days with AS should then have significantly higher PS scores. Secondly, the result is also in contrast to the notion that AS may in other cases allow for anticipatory coping. In that case, days with AS should have significantly lower PS scores. Theoretically, several avenues of anticipatory coping are possible (Lazarus & Folkman, 1984), including avoiding the stressor, planning for it, encouraging oneself, talking to friends, and not least, doing physical activity. Physical activity has been suggested to be an effective coping strategy through changes in affect, self-confidence, or social support (Dahlstrand et al., 2021; Kim & McKenzie, 2014; Taylor & Master, 2011). However, the interaction between PA and AS did not significantly predict PS, suggesting that PA does not moderate this relationship. It can thus not be assumed that PA increases resilience, be it through direct, or indirect pathways. In conclusion, neither H_3 nor H_4 are supported.

Physical activity (split by intensity level)

This study's other aim was to examine the relation between daily PA and PS, to test whether PA is positively associated with PS (H_1), and to test whether this association held true for MVPA, but not for LPA (H_2).

In the model that included PA as a singular variable, PA did not significantly predict PS. This means that no stress-buffering effect of PA was found, H_1 can thus not be supported. This is

in contrast to current literature, which found stress-buffering effects of PA (e.g. Fuchs & Gerber, 2018; Gerber & Fuchs, 2020; Mücke et al., 2018; Schultchen et al., 2019).

The insignificant results hold true even after PA had been split into LPA and MVPA. The absence of stress-buffering effects of PA only contributes to the contradictory state of current research. Literature suggests a dose-response relationship, with some findings suggesting a stress-buffering effect of LPA, but most findings existing only on exercise / MVPA. However, in this study, neither MVPA nor LPA were predictive of PS (hence, H_2 cannot be supported). As a result, it did not become clearer whether any amount of PA might have a stress-buffering effect (as in (Dahlstrand et al., 2021), or if there is a threshold that needs to be reached for any stress-buffering effect to occur (as in (Sothmann et al., 1996). Even though exercise is found to have stress-buffering effects in most of the literature (e.g. (Gerber & Pühse, 2009), the current study was not able to find a significant effect for MVPA. A look at the slope estimates allows a glimpse of what direction the effects *might* take. The slopes of PA and MVPA are, albeit minimally so, negative, suggesting that on days when more PA and MVPA were done than on an average day, PS scores were lower.

Covariates

While none of the independent variables were found to significantly interact with PS, some of the included covariates did in fact show significant effects. As a reminder, Trait PA, chronic stress, and trait depression were included as covariates. Two of those showed significant effects in model 8 (see table 4), namely trait PA, b = -0,07 (SE = 0,01; 95% − CI [-0,11 ; -0,04]), $t(5{,}61) = -5{,}37$, $p = ,002$; and trait depression, b = 0,55 (SE = 0,11; 95% − CI [0,31 ; 0,79]), $t(11{,}33) = 4{,}98$, , $p < ,001$. It seems as if it is not so much the daily minutes of PA one engages in that influence daily stress, but moreso how much PA one engages in regularly. Previous reviews were able to show that individuals who engage more in regular exercise, and those who are higher in physical fitness, showed reduced stress reactivity (Gerber & Pühse, 2009; Mücke et al., 2018), though studies have yet to be done that examine this effect for daily stress. Furthermore, it is surprising that chronic stress was not able to predict daily stress, as the concepts are conceptually linked (higher daily stress accumulates into a higher chronic stress level). On the other hand, depression scores did predict daily stress levels. It is possible that the insignificant

effects of chronic stress may be explained by a mediation through depression scores, as depression is associated with chronic stress (Gutman & Nemeroff, 2011).

Limitations and implications for future research

There are several limitations regarding this study's sample. First, it included only seven complete participants, leading to low power. Larger samples will improve the power of the study, and additionally allow for examination of between-person effects. As an example, future EMA studies could examine whether individuals who generally do more PA in their daily lives are more likely to have lower perceived stress (PS) scores, or how depression scores and chronic stress might interact. The current sample only included one male participant; future studies may additionally investigate gender differences. Additionally, this sample consisted of mostly students. As this population group shows moderate to high stress levels (Herbst et al., 2016), ceiling effects are possible. The reduced variance in PS could in part explain the difficulty of finding any significant effects. PA also decreases with age (Dahlstrand et al., 2021), and so effects of PA on PS could be investigated in older populations specifically. For future studies, a sample more representative in age, gender, and stress levels should be used.

In addition, there are limitations in the methodology. Firstly, AS was only assessed via one binary item. A separate item *was* included to assess what kind of stress participants were anticipating any given day; however, the answers differed in quality and intensity of the anticipated situation and was thus not analyzed in this study. One participant anticipated stress on most of the days. Only, the anticipated stressor was either going to university or work. Another participant reported that their anticipated stressor was that they would skiing on one day, while another anticipated an exam and yet another anticipated a long day. In the current form, both positive and negative events, extraordinary as well as ordinary events could all be described to answer what stress or challenge was expected. It is recommended for future studies to use a visual analog scale to assess the magnitude of the AS and use a narrower definition of AS to aid quantitative analysis. Moreover, while it was assessed whether individuals anticipated a stressor or not, it was not assessed whether a stressful event had happened or if a prediction came true. Predicting that a stressor would occur was found to be more accurate than predicting

that no stressor would occur (Scott et al., 2019). The difference in predictions of stress versus predictions of no stress could thus not be controlled for. Future studies may need to assess both the predictions and the outcome of the predictions when assessing the effects of AS.

Secondly, there are several considerations regarding physical activity assessment. The IPAQ-SF does not assess the context or purpose of the physical activity. In addition, MVPA was assumed to be equivalent to exercise. However, this might not be the case; some authors have suggested that stress buffering occurs because exercise is done voluntarily, and because it involves and improves implicit motivation and self-efficacy (Edenfield & Blumenthal, 2011; Isoard-Gautheur et al., 2019; Stults-Kolehmainen & Sinha, 2014). Moreover, exercise (in German literature also: sports) sometimes involves social contact (Fuchs & Gerber, 2018; Gerber & Fuchs, 2020). Social contact has been suggested to act as a stress buffer by itself and as a mechanism in relation to physical activity (Gerber & Fuchs, 2020; Taylor & Master, 2011). While exercise carries the connotation of a voluntary, goal-oriented, social activity, MVPA does not have to be goal-driven or voluntary, or social. MVPA does not make any limitations regarding the goal or context of an activity. Thus, stress-buffering effects may more so be found for exercise, may be "watered down" by assessing the broader term of MVPA and may be unable to be detected. Furthermore, physical activity is overestimated when using self-report measures as compared to an accelerometer measure (Gaede-Illig et al., 2014). It is recommended that further research utilize both self-report measures and objective measures of PA. Context (work, leisure, commute, etc.) and goal (voluntary or not) should additionally be included as measures, in order to compare assessments of PA, MVPA, and exercise.

Physical activity was only assessed once, at the end of a day. It is possible that the effects of PA are relatively short-term and do not radiate to a later time. Momentary measurements and daily diary reports have been found to correlate weakly when measuring between days less salient, everyday events (Kamarck et al., 2011). This description may apply to PA, as it is done every day and usually only salient when it is in the context of a competition, for example. Higher temporal resolution of measurements may provide additional data and remedy these limitations but would lead to a potentially unnecessary burden on participants, particularly for studies lasting several weeks. Future researchers should gauge participant burden against their research interests and use additional perceived and psychological stress measures.

Participants were asked to report daily PS when they felt like their day ended or before they went to bed. This could arguably lead to the problem that participants only saw their day as having "ended" when stress levels have already dropped off and they felt relaxed. This could possibly lead to a bias towards lower reported levels of stress. I should also note that instructing participants to complete the evening questionnaire in this way led to some participants not reporting as intended. On some days, participants ignored prompts for the evening questionnaire in the afternoon and evening and only completed them late in the night or the next morning. This lagged reporting may not have as much of an influence on objective measures such as how many minutes of PA one engaged in the previous day, but it might have a significant impact on subjective measures like PS.

The current thesis has only examined differences between levels of physical activity but did not include sedentary activity. Physical activity is able to offset the negative effects of sitting on health (World Health Organization, 2020), and differences in stress have particularly been found between sitting and LPA (Schnohr et al., 2005). SED may moderate or mediate the stress-buffering relationship between PA and PS (Dahlstrand et al., 2021; Dėdelė et al., 2019; E. Lee & Kim, 2019; Schnohr et al., 2005; Teychenne et al., 2019). Future studies should examine this, as well as the question of whether higher levels of PA are better able to offset the effects of SED.

Conclusion

Given the unclear state of the literature, a conclusion about the validity of physical activity as a stress-buffering tool, both direct or indirect, would be problematic. The same can be said for the relationship between AS and PS. Further studies are needed to test these relationships. This study should not be understood to disprove current literature. As there are methodological and sampling limitations, results of this study should be considered with caution. Conclusions can thus only be drawn based on already available literature. Exercise can relatively safely be assumed to buffer stress and its consequences; similar statements cannot be made of physical activity. Anticipating stressors leads to stress and thus increases the total amount of stress, except when it leads to successful anticipatory coping. The exact mechanisms of this relationship remain unclear.

Even if physical activity in general might not play a stress-buffering role, exercise does. And physical activity of any kind still brings with it physical health benefits, both acutely and as we age (Berger, 1994; World Health Organization, 2020). Public health policy should thus still aim to decrease the amount of sedentary activity and increase the amount of physical activity that the public engages in, be it through reducing car-dependency or increasing access sports activities. In conclusion, individuals should not dismiss exercise and physical activity, even if the exact mechanisms for positive effects are not yet clear if on a population level. Walking up that flight of stairs may not alleviate stress, but it would not hurt to try.

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Tables

Abbreviations

-2LL	-2-log-likelihood
ANS	autonomic nervous system
AS	anticipatory stress
EMA	ecological momentary assessment
GAS	general adaptation syndrome
HPA (axis)	hypothalamus-pituitary-adrenal (axis)
IPAQ (-SF)	International physical activity questionnaire (short form)
LPA	light (intensity) physical activity
LTPA	leisure-time physical activity
MPA	moderate (intensity) physical activity
MVPA	moderate-to-vigorous (intensity) physical activity
MLM	multilevel modeling / multilevel model
PA	physical activity
PS	perceived stress
PSS (-4)	Perceived Stress Scale (form with four items)
SED	sedentary activity
TSST	Trier Social Stress Test
VPA	vigorous (intensity) physical activity

Appendix 1: Study recruitment poster

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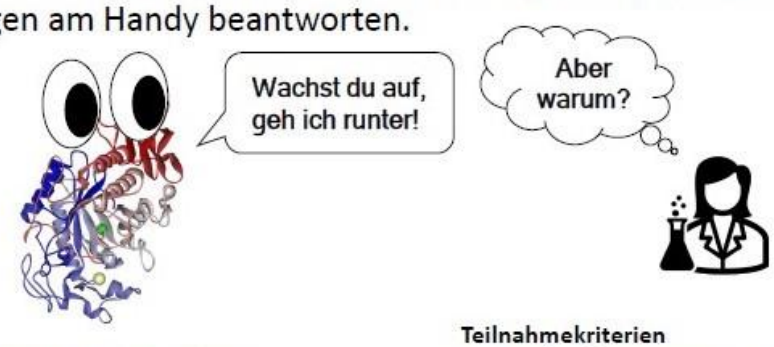
ProbandInnen gesucht für Studie zu „Messung von Stress im Speichel“!

Für eine psychologische Studie suchen wir aktuell gesunde Teilnehmerinnen und Teilnehmer. Die Studie untersucht die Bedeutung der Morgenaufwachreaktion von Alpha-Amylase, einem Verdauungsenzym im Speichel, das bei Stress ansteigt. Die Studie findet bei Ihnen zuhause im Alltag statt. Für die Dauer eines Monats oder eines Menstruationszyklus würden Sie innerhalb der ersten 30 Minuten nach dem Aufwachen drei Speichelproben sammeln und Fragen am Handy beantworten.



Aufwand und Entschädigung

- Für die Dauer von 30 Tagen bei Männern/einem Menstruationszyklus bei Frauen: Speichelproben (3x pro Tag) und Fragebögen (morgens und abends)
- Beantworten von Fragen zu Stress, Stimmung, Lifestyle und Menstruation.
- Aufwandsentschädigung von 100€

Teilnahmekriterien

- Regelmäßiger Menstruationszyklus, keine hormonelle Verhütung
- Derzeit nicht schwanger und nicht stillend
- Kein Unter- oder Übergewicht, keine körperlichen oder psychischen Erkrankungen.
- Fließende Deutschkenntnisse
- 18-35 Jahre alt
- Kein regelmäßiger Nikotinkonsum

Bei Interesse Email an

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Projektleitung: Univ.-Prof. Dr. Urs Nater (urs.nater@univie.ac.at)
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Abstract

Stress encompasses changes in biology and psychology that occur when one faces a challenging or threatening situation. Current research suggests exercise to have a stress-buffering effect. However, it is unclear if the broader concept of physical activity is able to buffer stress as well. Additionally, anticipating stress causes stress itself, which acts additively actually experienced stress. However, in resilient individuals and in cases where anticipatory stress leads to successful anticipatory coping, it may instead lead to a reduction in experienced stress. Physical activity is an example for anticipatory coping and is associated with resilience. To examine the effects of physical activity and anticipatory stress on perceived stress in daily life, seven healthy individuals were recruited who participated in an ecological momentary assessment study for 25-35 days. Effects of physical activity and anticipatory stress on perceived stress, as well as moderating effects of physical activity on the relationship between anticipatory stress and perceived stress, were analyzed using multilevel modeling. In addition, differences between different physical activity intensities were analyzed. Contrary to expectations and literature, daily physical activity and anticipatory stress were not associated with lower daily stress. Physical activity did not moderate the relationship between anticipatory stress and perceived stress. This was the case even after physical activity had been split into different activity levels. Limitations and implications for future studies are discussed.

Keywords: physical activity, stress-buffering, anticipatory stress.

Zusammenfassung

Stress umschreibt biologische und psychologische Veränderungen, die in herausfordernden oder bedrohlichen Situationen auftreten. Aktuelle Forschungsergebnisse deuten darauf hin, dass Sport bzw. körperliche Betätigung eine stresspuffernde Wirkung haben. Jedoch ist es unklar, ob das umfassendere Konzept der körperlichen Aktivität ebenfalls Stress puffern kann. Die Antizipation von Stressoren führt zu Stresserleben, das sich mit tatsächlich erlebtem Stress addiert. Doch bei resilienten Personen und in Fällen, in denen antizipatorischer Stress zu erfolgreichem antizipatorischem Coping führt, kann es stattdessen zu einer Verringerung des erlebten Stresses kommen. Körperliche Aktivität ist ein Beispiel für antizipatorisches Coping und steht mit Resilienz in Verbindung. Zur Untersuchung der Auswirkungen körperlicher Aktivität und antizipatorischen Stress auf das Stressempfinden im Alltag wurden sieben gesunde Personen rekrutiert, welche 25-35 Tage lang an einer *Ecological Momentary Assessment*-Studie teilnahmen. Die Auswirkungen von körperlicher Aktivität und antizipatorischem Stress auf das alltägliche Stressempfinden, sowie die moderierenden Effekte von körperlicher Aktivität auf die Beziehung zwischen antizipatorischem Stress und Stressempfinden wurden mit Hilfe von Mehrebenenmodellen analysiert. Zusätzlich wurden Unterschiede zwischen verschiedenen Intensitäten körperlicher Aktivität analysiert. Entgegen den Erwartungen und entgegen der Literatur waren tägliche körperliche Aktivität und antizipatorischer Stress nicht mit geringerem täglichem Stressempfinden verbunden. Körperliche Aktivität moderierte nicht die Beziehung zwischen antizipativem Stress und Stressempfinden. Dies war auch der Fall, nachdem körperliche Aktivität in verschiedene Intensitäten aufgeteilt worden war. Einschränkungen und Implikationen für zukünftige Studien werden diskutiert.

Stichworte: körperliche Aktivität, Stresspufferung, antizipatorischer Stress