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Psychophysiology, Performance, and Training Under Stress in Police Service

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Abstract

Police officers perform far-reaching actions while facing a variety of operational and organizational stressors. Although acute psychophysiological stress responses can be adaptive, chronic or frequent stress might alter officers' physiological functioning. Critically, stressful situations are often associated with performance failures, especially when resources are depleted. Hence, the essential challenge for police training is to teach skills that transfer to high-stress situations. To protect police officers' occupational performance and long-term health, the dissertation aimed at gaining a comprehensive understanding of stress processes in police service and using the insights to design evidence-based training methods. Building on the cognitive appraisal theory, in Manuscript 1, the psychological appraisal processes underlying perceived stress in police service were assessed in a mixed-methods online survey in a sample of 2567 European police officers during the COVID-19 pandemic. Inter-individual differences in stressor appraisal and perceived coping resources explained the large inter-individual variance in self-reported stress. Manuscript 2 focused on the idiosyncratic associations of perceived stress and physiological stress markers of a 28-year-old male police officer in an ecological momentary assessment over three weeks (90 data points). The daily profiles of salivary cortisol and alpha-amylase were dysregulated suggesting a state of allostatic load. Pointing to hyporesponsivity, cortisol and alpha-amylase were not related to perceived stress in daily life and did not increase in police incidents. The preregistered study in Manuscript 3 investigated the influence of emotional and physical stress on response inhibition in a sample of 24 university students. Contrary to the predictions by the attentional control theory, neither emotional nor physical stress significantly altered inhibitory performance. Based on the constraints-led approach, Manuscript 4 presented a literature-based analysis of strengths, weaknesses, opportunities, and threats associated with the implementation of police training under stress in Virtual Reality. Building on the empirical findings, Manuscript 5 demonstrated how evidence on perceived stressors can inform police training under stress. Together, the results of the dissertation point towards a discrepancy between psychological, physiological, and behavioral stress responses, potentially mediated through interindividual differences in stress reactivity and stress-dose effects. Adressing the complexity of stress in police training provides officers with the opportunity to actively engage in coping, adapt to stressors, and eventually grow from stress. To bridge the gap between science and practice, further research is needed to facilitate the implementation of evidence-based training methods into police service.

List of Scientific Publications of the Publication-Based Dissertation

Manuscript 1
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Manuscript 2
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Manuscript 3
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Manuscript 4
Giessing, L. (2021). The Potential of Virtual Reality for Police Training Under Stress: A SWOT Analysis. In: E. A. Arble & B. B. Arnetz (Eds.), *Interventions, Training, and Technologies for Improved Police Well-Being and Performance* (pp. 102-124). IGI Global. https://doi.org/10.4018/978-1-7998-6820-0.ch006

Manuscript 5
Frenkel, M. O., Giessing, L., Jaspaert, E., & Staller, M. (in press). COVID-19 Specific Police Training: Preparing for Pandemic-Induced Demands. *European Law Enforcement Research Bulletin*.

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1 Introduction

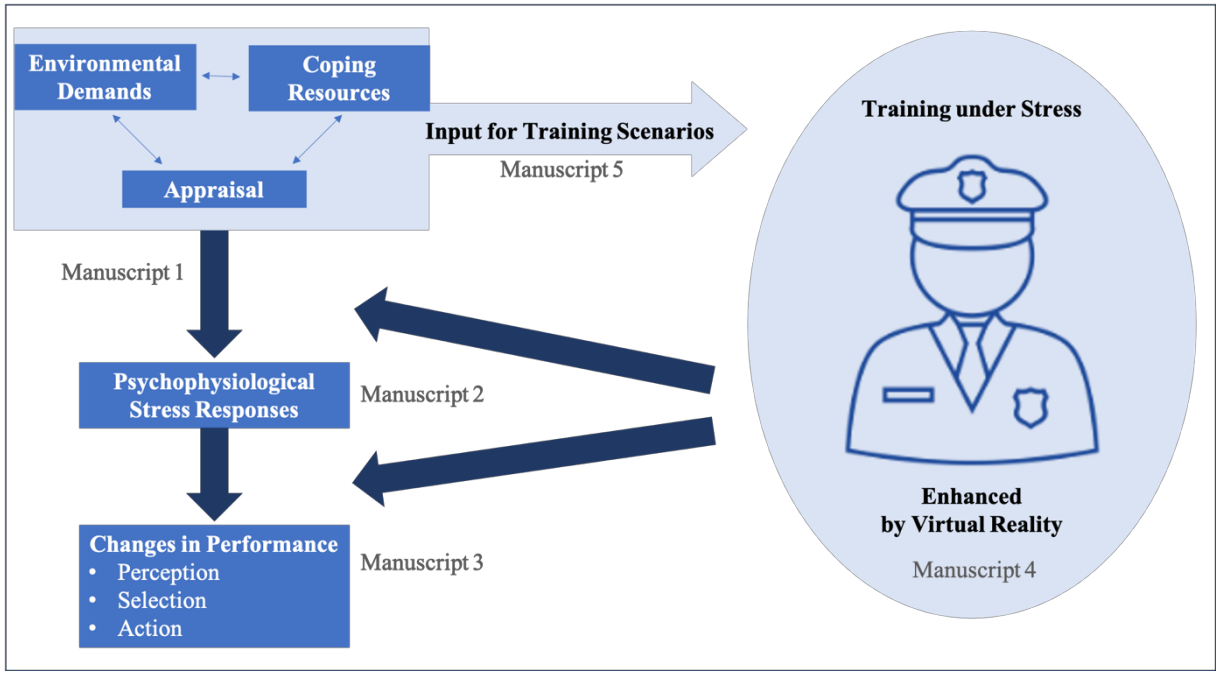
Civil security is a fundamental precondition for freedom, democracy, economic wealth, and social peace, which has been threatened by societal phenomena, such as international terror attacks (Nizza, 2017; Paris, 2016; Berlin, 2016), riots based on radicalization in the right- and left-wing movements (Hamburg, 2017; Chemnitz, 2018), and racist attacks (Halle, 2019; Hanau, 2020). Police officers are entrusted with the task to ensure civil security, in some cases necessitating the use of (lethal) force. Performance failures in these situations may have severe consequences for suspects, innocent bystanders, colleagues, or the officers themselves. Therefore, it is intolerable for police officers to act outside the legal and ethical framework. Police officers are expected to self-regulate their emotions, attention, and behavior in order to apply proportionate use of force at any time. However, police officers usually make the most far-reaching decisions and perform the most critical actions in highly stressful, unpredictable, ambiguous, and rapidly unfolding situations. Maintaining goal-directed behavior under these circumstances is difficult and performance decrements under stress are well documented across the wider applied literature (Eysenck et al., 2007; Nieuwenhuys, & Oudejans, 2012, 2017). Therefore, the primary objective of police training is to teach occupationally relevant skills and tactics in a way that police officers can reliably recall them even under high-stress circumstances on police duty. To effectively train police officers in maintaining goal-directed behavior in high-stress situations, it is vital to examine the psychological and physiological stress processes that influence performance and use this knowledge to design evidence-based training methods that contribute towards improvement.

This dissertation aimed at providing a comprehensive understanding of psychophysiology, performance, and training under stress in police service (see Figure 1). First, human factors influencing police officers` stress responses were identified. Previous insights on occupational stressors in police service (Violanti et al., 2016, Sherwood et al., 2019) were enriched by considering the role of perceived coping resources in the appraisal process (Lazarus & Folkman, 1984). Specifically, the COVID-19 pandemic as a global, prolonged critical incident constituted a promising opportunity to assess perceived stressors and coping resources and to quantify their impact on perceived stress levels (see Manuscript 1). Moving beyond psychological appraisal processes, the intertwined nature of acute and chronic physiological stress processes was examined in a N-of-1design by employing ecological momentary assessments throughout a three-week period (see Manuscript 2).

Neurophysiological changes under stress are assumed to impair performance due to a shift from goal-directed to stimulus-driven processing (Eysenck et al., 2007; Hermans et al., 2014; Nieuwenhuys & Oudejans, 2012, 2017). In this regard, the ability to inhibit prepotent responses under physical and emotional stress was investigated by employing a stop-signal task in a preregistered laboratory study (see Manuscript 3). Finally, practical implications of the reported empirical findings were outlined by demonstrating how they can contribute to evidence-based police training. Given the stressful nature of police service, the constraints-led approach (Davids et al., 2008) was proposed as promising approach to police training under stress (Low et al., 2020). Based on a literature-based analyses of strengths, weaknesses, opportunities, and threats, virtual reality was critically discussed as a tool to effectively implement the constraints-led approach into police training (see Manuscript 4). As a best practice example of evidence-based police training, the study results on the police officers' perceived stressors during the COVID-19 pandemic were re-analyzed to inform representative scenario development in police training (see Manuscript 5). Thus, the following dissertation presents a thorough examination of the role of stress in police service, including both theoretical advances for stress research and practical implications for police training.

Figure 1

Flow Chart of the Main Research Topics



2 Appraising and Coping with Stress in Police Service

Policing is considered as one of the most stressful occupations by academic researchers, police practitioners, health-care professionals, and psychologists. Indeed, police officers operate in highly complex environments which can exert a major influence on them and their performance. Although it may be appealing to directly delve into examining how police officers perform in critical incident, it is fundamental to first comprehensively understand the environmental demands that precede and accompany their performance. This plea is in accordance with early, stimulus-based definitions of stress (Cannon, 1914), in which the environmental demands requiring individuals to adapt are emphasized. However, in the recent literature, interaction- and transaction-based conceptualizations of stress take into account the individual that operates in a specific environment. In these approaches, stress experiences are described as idiosyncratic. The extent to which stress has beneficial or detrimental effects on well-being and performance largely depends on the individual's appraisal of the environmental demands (Lazarus & Folkman, 1984).

2.1. Theory of Cognitive Appraisal

According to the theory of cognitive appraisal (Lazarus & Folkman, 1984), stress results from an ongoing transaction between an individual and the environment: Environmental demands trigger two discrete, but interdependent cognitive processes, which can either be conscious or subconscious (Lazarus, 1991). In the *primary appraisal process*, the individual judges the significance of the situation for their well-being regarding goal relevance, goal congruence, and type of ego involvement (Lazarus, 1999): the environment can either be appraised as irrelevant, benign-positive, or threatening to the goals. Environments are appraised as irrelevant if they have no implication for well-being and thus, no potential for loss or gain. Benign-positive environments are perceived as having the potential to enhance the individual's well-being, whereas stressful environments are perceived as threatening to the individual's well-being and turn the environmental demands into *stressors*. Based on a probabilistic approach, stressors are demands or situations that increase the likelihood of experiencing stress in "a reasonable proportion of people" (Spector & Goh, 2001, p. 203). Whether stressors do result in the experience of stress or not depends on the outcome of the *secondary appraisal process*. In the complex process of secondary appraising, the individual considers the degree of control over the stressors, which coping resources are available, their ability to effectively employ a given coping strategy, and the likelihood of this

strategy to successfully overcome the demands (Lazarus & Folkman, 1984). Depending on the outcome of the secondary appraisal process, the encounter with a stressor can result in four possible transactional alternatives: benefit, harm/loss, challenge, or threat (Lazarus, 1999; Lazarus & Folkman, 1984). *Benefit* and *harm/loss* refer to an enhancement of or damage to well-being that has already occurred. *Challenge appraisals* arise when the available coping resources are judged as sufficient to overcome the stressors, and thus, a gain may result from the situation. In contrast, *threat appraisals* arise when environmental demands are perceived as exceeding the coping resources, and thus, damage to the individual's well-being is anticipated. In turn, the transactional alternatives result in emotions that vary in quality and intensity according to the individual's primary appraisal and secondary appraisal. For instance, while challenge appraisals typically elicit positive emotions such as eagerness and excitement, threat appraisals often elicit negative emotions such as fear, anxiety, and worry (Folkman, 2013). Although transactional alternatives elicit distinct cognitive and affective processes, they may occur simultaneously, and the relationship between them can shift as the situation evolves.

Coping refers to the process of managing the discrepancy between perceived demands and resources. To reduce stress, the individual makes use of cognitive and behavioral efforts to master, reduce, or tolerate the perceived stressors (Lazarus & Folkman, 1991). Broadly, two types of coping strategies can be distinguished, which are to be applied depending on the results of the cognitive appraisal: problem-focused and emotion-focused coping. Problem-focused coping is usually used in situations that are controllable. It aims at changing the problem-causing circumstance or expanding the individual's resources (e.g., planning to solve the problem). In contrast, emotion-focused coping aims to regulate stress-associated emotions (e.g., positive reinterpretation) and is typically applied in low-control situations which have to be accepted. Generally, most real-life situations involve more than one coping task or goal, therefore requiring individuals to use a variety of coping strategies and flexibly shift between coping strategies. Importantly, coping is part of the ongoing person-environment transaction that reciprocally influences the individual's appraisals, their experiences and emotions during the situation, and their coping efforts. Appraisals and coping are constantly updated and may change rapidly under certain circumstances (i.e., *re-appraisal*; Lazarus & Folkman, 1984). If the coping resources are appraised as sufficient to meet the demands, the degree of threat in the first appraisal is reduced. Vice versa, an initially challenging environment can become threatening if coping resources turn out to be inadequate for overcoming the demands. As a result, coping effectiveness is highly contextual. In this ongoing transaction between an

individual and their environment, emotions are considered as an outcome providing tremendous diagnostic value for the individual's coping success in a particular context (Folkman & Lazarus, 1991): As the individual's appraisal of a situation will change, so will the intensity and value of their emotions. In this regard, researchers often identify a desired coping outcome a priori, e.g., improved mood, and achieving the desired outcome indicates successful coping.

In sum, many personal and situational variables interact to determine whether an incident is perceived as stressful or not, resulting in a large inter- and intra-individual variability in cognitive and emotional stress experiences. Additionally, stress must be understood as a dynamic process with rapid changes during the appraisal processes, coping efforts, and emotional experiences. To fully understand police performance under stress, the environmental stressors as well as the officers' appraisals need to be considered.

2.2. Occupational Stressors in Police Service

As a human-service job with the responsibility to protect lives of citizens, police officers are frequently exposed to human misery, experience threats to their safety and wellbeing, and bear responsibility of carrying firearms. The daily activities are under constant scrutiny due to the societal and political expectations, while organizational resources such as personnel or equipment are limited (Violanti et al., 2016). Broadly, occupational stressors associated with police work have been classified into two categories: *operational and organizational stressors* (Sherwood et al., 2019). The former is associated with the very nature of police work, including critical or traumatic incidents threatening the officers' psychological and physical health. The latter is related to organizational administration, management, structure, and processes within the police organization.

Operational stressors usually occur during critical police incidents resulting in a sudden onset of high-intensity stress. In these situations, police officers' coping resources are overwhelmed by the sudden and intense demands of the environment, eliciting acute stress (Anderson et al., 2002). Most of the operational stressors reported by police officers dealt with violent situations (Violanti & Aron, 1994, 1995; Violanti et al., 2016). Killing someone on duty, witnessing a fellow officer being killed, being physically attacked, and seeing abused and battered children were rated as the top four of sixty most stressful police work events (Violanti & Aron, 1994, 1995; Violanti et al., 2016). Given the rare occurrence of these stressors, it might be worthwhile to consider the occurrence probability of the stressor (i.e., how often the officer has encountered the stressor in a specific unit of time; see Spielberger et

al., 1981) in addition to its intensity. Stressors occurring frequently might actually contribute to police stress more strongly, even if they are not rated as highly intense. Among the top five most stressful events with higher occurrence probabilities ranked domestic violence, physical attacks, and the use of force (Violanti et al., 2016). Usually, critical incidents are resolved in a short duration and the experience of stress is temporary, ending as soon as the critical situation is resolved. Thus, operational stressors can be considered as *acute stressors*.

In contrast, organizational stressors continue to be present on a daily basis throughout the entire police career, constituting them as *chronic stressors*. Chronic stressors have been suggested to be as impactful as operational stressors, if not more (Sherwood et al., 2019). Especially, shift work, long working hours, work overload, and low levels of reward and social support have been identified as central organizational stressors in police service (Anderson et al., 2002; Sherwood et al., 2019). Other factors related to the organizational management include the lack of administrative support, inadequate training or equipment, excessive paper work, intra-departmental politics and frustrations with the criminal justice system and court leniency (Anderson et al., 2002; Violanti et al., 2016).

While there seems to be a consensus about the presence of various stressors in police work, the (perceived) availability of coping resources is often neglected in this line of research. Asking about the presence, frequency, and intensity of a stressor in a surrounding environment can be helpful in the identification of potentially relevant work stressors (Dewe, 1991). Still, it wrongly assumes that the presence and intensity of a stressor automatically elicits corresponding stress responses. As a result, the impact of specific occupational stressors on police officers might be overrated, if officers have sufficient coping resources to meet these stressors. To overcome this, it is crucial to identify the stressors for which officers currently lack adequate coping resources. Developing a realistic understanding of officers' stress by taking into account their perceived coping resources will enable to provide officers with more targeted support in coping with stress. In Manuscript 1, we aimed to expand the knowledge of the existing stressors (Sherwood et al., 2019; Violanti et al., 2016) and used the COVID-19 pandemic as a real-life setting to investigate the triangle of occupational stressors, coping resources, and perceived stress in police service.

2.3. Stress, Demands, and Coping Resources in Police Service During the COVID-19 Pandemic (Manuscript 1)

Starting in spring 2020, the COVID-19 pandemic has continued to be one of the greatest challenge the world is currently facing. In order to protect public health, governments around

the world have enacted unprecedented measures. Law enforcement agencies and street patrol officers have been responsible for enforcing these measures, maintaining public order and promoting safer communities (Brito et al., 2009). As such, policing during the COVID-19 pandemic can be considered a "critical police incident" (although of longer duration and geographical impact than usual police incidents; Jennings & Perez, 2020), requiring the officers to respond to novel, uncertain, uncontrollable, and threatening situations (Stogner et al., 2020). Some of the well-known police stressors have taken different forms during the pandemic, e.g., risk of infection as a constant threat to physical integrity (Drake & Altheimer, 2020; Jennings & Perez, 2020; Milliard & Papazoglou, 2020; Stogner et al., 2020), or spitting attacks as a new type of threatening and hazardous behavior by assailants (Jennings & Perez, 2020). Other existing stressors have been exacerbated by the pandemic, e.g., higher workload caused by staff shortage due to infected and quarantined officers (Drake & Altheimer, 2020; Milliard & Papazoglou, 2020) and more frequent high-stress encounters with anxious or intransigent individuals aggravated by the fear of infection, economic uncertainty, and isolation. Given the little research on the complete appraisal processes in police context, we used the COVID-19 pandemic as a real-life setting (1) to test whether commonly found police stressors can also be found during the pandemic, (2) to identify the perceived individual, organizational, and governmental coping resources, and (3) to examine how they interact to determine police officers' stress.

At the outbreak of COVID-19, the development of the pandemic as a *stressor* and the effectiveness of governmental, organizational and individual measures as *coping resources* were unclear. We assumed that officers' stress experience would vary over the course of the pandemic depending on the development of the pandemic and the effectiveness of the measures. To reveal how officers were coping at each specific time point, we repeatedly measured European police officers' perceived stress, mood, and fatigue (collectively representing their *strain*) at four measurement points throughout an 11-week period from March 27, 2020 to June 5, 2020. Accounting for the nested data structure of 2567 police officers from Austria (n = 1415), Germany (n = 711), Switzerland (n = 325), the Netherlands (n = 76), and Spain (n = 40), we examined the changes in strain since the first day of the national lockdown in three-level growth curve models. Following our attempt to capture the entire appraisal process, we assessed the primary appraisal of the pandemic as stressful, challenging, controllable, and threatening, as well as various personal factors as part of the secondary appraisal process. Based on the occupational stress literature, these personal factors included sex (Bowler et al., 2010; Violanti et al., 2016), work experience (Landman et al.,

2016), preparedness through training, and the use of emotion regulation strategies (Katana et al., 2019)[1].

Our results showed that overall, the majority of the officers seemed to tolerate the demands caused by the pandemic. On the first day of the lockdown, the "average" officer (male, 17.22 years of work experience) had a medium strain level of 3.56 on a scale ranging from 1 to 7. Given the significant decrease of strain over three months after the lockdown (Estimate = - 0.02, $p < .01$), one might speculate that strain might have been elevated at the beginning of the lockdown compared to non-pandemic times. However, our data allows no such direct comparison and therefore, this interpretation should be treated carefully. Neither stress appraisal of the COVID-19 pandemic nor emotion regulation and preparedness through training significantly interacted with days since the lockdown. Therefore, it remains unclear whether changes in the appraisal of the pandemic as a stressor or changes in the (perceived) effectiveness of the coping resources caused the decrease in officers' strain. Since officers generally experience elevated stress levels (Allison et al., 2019; Planche et al., 2019) and changes in strain were rather small, one might assume that the "average" officer was only moderately affected by the pandemic. Nevertheless, most of the variance in the observed strain levels occurred between individuals (66 %), highlighting the importance of personal factors (such as being female; Estimate = 0.22, $p < .001$) in the stress transaction. The (primary) appraisal of the pandemic as stressful significantly increased reported stress levels (Estimate = 0.46, $p < .001$). Regarding the secondary appraisal process, feeling prepared through training (Estimate = - 0.10, $p < .001$), work experience (Estimate = - 0.01, $p < .01$) and adaptative emotion regulation (Estimate = - 0.09, $p < .05$) were identified as coping resources associated with lower stress levels, whereas maladaptive emotion regulation (Estimate = 0.16, $p < .001$) was a risk factor for high stress levels.

To gain a proper understanding of the underlying transaction between stressors and coping resources, we supplemented the quantitative results with insights into the lived experience of police officers by incorporating open-ended questions. Free response answers on their main tasks, work stressors, effective crisis measures, effective crisis prevention, and lack of coping resources were analyzed using the deductive category assignment in the qualitative content analysis (Mayring, 2014). The officers' reports revealed two environmental demands as major work stressors, especially at the beginning of the pandemic: risk of infection as a threat to the officers' integrity and information overload (for similar

[1] For a more detailed description of the study's materials and results see Appendix A1.

results in health care professionals see Frenkel et al., 2021). Together with the significant influence of the personal factors in the quantitative analysis, these findings are in line with theories conceptualizing stress as a person-environment transaction (Lazarus & Folkman, 1984). Despite these stressors, officers' reports about the effective crisis measures and wishes for support revealed that they seemed to perceive adequate coping resources to meet the stressors associated with the COVID-19 pandemic. Particularly, training experience was mentioned as an important coping resource and the significant result of the growth curve model (i.e., feeling prepared) affirmed these impressions. Self-protection by keeping distance, target-oriented communication, quick decision-making, and stress regulation acquired during scenario-based training were reported as useful skills to meet the pandemic-specific demands (for a more detailed description of the relevance of these findings for police training see Manuscript 5).

In conclusion, the presented study has highlighted the pivotal role of both primary and secondary appraisal processes including influential situation and person factors in the determination of perceived stress among police officers. Despite the presence of various work stressors during the COVID-19 pandemic, the average police officer only reported medium stress levels. Presumably, perceived coping resources, such as police-specific skills acquired during training can prevent police officers from experiencing high stress levels. Nevertheless, the large interindividual variability in stress has directed attention to the importance of personal factors. Given the practical significance of appraisals for health, well-being, and performance, preventive mental health interventions can start at changing the conscious and subconscious thoughts about stressors by increasing perceived coping resources.

3 Psychophysiological Stress Processes in Police Service

Besides the emotional responses, appraisals also pave the way for physiological and behavioral outcomes with important consequences for performance, well-being, and health. Exposure to stressors destabilizes the bodily homeostasis, resulting in a cascade of physiological processes (Kemeny, 2003). Since the description of the *general adaptation syndrome* in response to stressors by Hans Selye (1936), stress has been considered a double-edged sword: On the one hand, physiological changes in the stress systems are adaptive coping mechanisms in response to acute stress. On the other hand, they can cause damage and diseases when they persist over long periods of time. In police service, an adaptive psychophysiological stress reactivity is important for optimal functioning in critical incidents.

However, the frequent exposure to operational stressors and the persistent presence of organizational stressors might overstrain the functioning of the stress systems among officers, putting their performance and health at risk. So far, research on officers' psychophysiological stress responses has either focused on short-term acute stress reactivity during critical incidents (e.g., Arble et al., 2019; Giessing et al., 2019; Strahler & Ziegert, 2015) or on long-term physiological changes in the stress systems' functioning (e.g., Allison et al., 2019; Planche et al., 2019). A comprehensive approach that links these double-edged effects and provides insights into how officers respond to acute stressors against the background of chronic or repeated stress responses is lacking in the literature.

3.1. Acute Psychophysiological Stress Reactivity

In stressful environments, cognitive appraisal processes are made by the prefrontal cortex and limbic structures (particularly the hippocampus and amygdala). They are closely connected with the hypothalamus, the central hub in the coordination of the psychophysiological stress reactivity (Godoy et al., 2018). Threat appraisals result in the activation of the fast reacting sympathetic-adrenomedullary (SAM) system including the withdrawal of the parasympathetic nervous system (PNS) and the activation of the slower hypothalamo-pituitary-adrenal (HPA) axis. These responses are nonselective changes that help the organism to adequately deal with the stressor. They mobilize necessary and suppress unrequired physiological systems (Kemeny, 2003).

Under acute stress, the SAM system is activated within seconds and rapidly releases the neurotransmitter noradrenaline at various organ sites, including the adrenal medulla, causing the release of epinephrine (also known as adrenaline) into the bloodstream. This is often experienced as the "adrenaline rush" in stressful encounters (Kemeny, 2003). Associated physiological changes include an increase in heart and breathing rate, promotion of blood circulation in larger muscles, or activation of muscle fibers, collectively known as the *fight-or-flight* response (Cannon, 1914). As the antagonist to the sympathetic nervous system (SNS), the PNS is responsible for the body's function at rest, including digestion, activation of metabolic processes, and relaxation (*rest and digest*). For an adaptive stress response, it is therefore central that the inhibitory influence of the PNS is withdrawn to facilitate the recruitment of the SAM system (Porges, 2009).

If the stressor does not resolve immediately, an endocrine response will be initiated through the activation of the HPA axis approximately 3 min after stress onset. The hypothalamus secrets the corticotropin releasing hormone (CRH), which stimulates the

pituitary gland to release the adrenocorticotropic hormone (ACTH) into the blood stream. In turn, ACTH acts on its target organ, the adrenal glands, causing them to release cortisol. In contrast to the fast electrochemical signals in the SAM system, the hormonally mediated effects of the HPA axis via the blood stream are rather slow: Cortisol levels peak 20 to 40 min after stress onset and return to baseline level within 40 to 60 min after the end of the stressor (Dickerson & Kemeny, 2004). Under acute stress, the activation of the HPA axis supports normal physiological functions and regulates other systems within the stress response (Kemeny, 2003): Cortisol stimulates glucose production, mobilizes fatty acids to encourage higher blood sugar, and prepares for energy expenditure during prolonged stressor presence (Herman et al., 2016). As cortisol is lipophilic, it passes across the blood-brain barrier to act on the central nervous system (Hermans et al., 2014). To prevent an "overshooting" of the stress reaction, cortisol acts back on the hypothalamus and pituitary to inhibit CRH and ACTH production in a negative feedback loop system (Murison, 2016).

3.2. Allostasis and Allostatic Load Model

The process of the ongoing physiological adjustment to stressors mediated by catecholamines (adrenaline and noradrenaline) and glucocorticoids (cortisol) has been termed *allostasis* (Sterling & Eyer, 1988). It derives from the view that healthy functioning requires continual adjustments of the internal physiological milieu to the environmental demands. As such, allostasis is the ability of an individual to achieve stability through change (Sterling & Eyer, 1988). The increase in catecholamines and glucocorticoids trigger dynamic shifts in brain networks to increase attentional vigilance and excitability, mobilize energy resources and enhance rapid stimulus-response behavior (Hermans et al., 2014), all of which are critical to immediate survival in potentially or actually unsafe situations. These changes are adaptive when rapidly mobilized in response to acute stress and terminated when the stressor is no longer present. As a result, the systems return to baseline levels of catecholamine and glucocorticoids secretion. However, if the physiological changes do not revert after the stressor has passed, *allostatic load* refers to the price the organism pays for being forced to adapt to adverse stressors. This state of chronic stress ("wear and tear") will lead to dysregulation of the normally protective stress systems, i.e., hypoactivity of the HPA axis, sympathetic overdrive, and vagal withdrawal (McEwen & Stellar, 1993). Over the long-term, the dysregulation ultimately results in vulnerability to diseases and psychological dysfunctions through maladaptive effects on brain plasticity and metabolic, immune, and cardiovascular pathophysiology (Herman, 2013), known as *allostatic overload*. Four types of

allodynamic responses have been associated with the development of allostatic load or overload: (a) frequent exposure to stressors, (b) lack of adaptation or habituation to repeated stressors, (c) prolonged response due to the inability to shut off the stress response after a stressor is terminated, and (d) an insufficient allostatic response in response to a stressor (Mc Ewen & Stellar, 1993).

In sum, the physiological mediators are associated with both adaptation and pathophysiology. One the one hand, glucocorticoids and catecholamines facilitate the adaptation of the organism to acute stressors. On the other hand, they also contribute to pathological dysregulations over long periods of time. Therefore, the measurement of the physiological mediators in the course of both acute and chronic stress is necessary to get a comprehensive view of stress in terms of performance, well-being, and health (McEwen, 2000). The activation of the SAM system and the HPA axis both during acute and chronic stress can be assessed through salivary stress markers, namely salivary alpha-amylase (sAA; Nater & Rohleder, 2009) and cortisol (sCort; Kirschbaum & Hellhammer, 1994), respectively. Both markers show distinct diurnal patterns. The diurnal pattern of sAA levels is characterized by a pronounced decline within the first 60 min after awakening, steadily increasing during the course of the day (Nater et al., 2007; Rohleder et al., 2004). In the diurnal pattern of sCort, awakening causes a distinct spike 20 to 30 min after awakening, known as the cortisol awakening response (CAR; Prüssner et al., 1997). Thereafter, sCort levels decrease throughout the day with a nadir at bedtime (Hellhammer et al., 2009). Importantly, atypical diurnal or awakening patterns represent HPA axis dysfunctions (Mc Ewen & Stellar, 1993) and are associated with poor health outcomes (Adam et al., 2017). Given the diurnal variations in basal secretion and potential dysfunctions thereof, it is important to consider aspects of temporal patterning and baseline functioning when investigating the protective and damaging consequences of the physiological stress mediators in response to acute stress (McEwen, 2000).

3.3 Allostatic Load in Police Service

There is a growing consensus that an allostatic load model may apply in police service (e.g., Allison et al., 2019). Continuous exposure to organizational stressors and frequent exposure to operational stressors may be major contributors to sustained activation of the physiological stress systems among officers, ultimately resulting in dysregulations. Results of a meta-analysis show that ongoing physically threatening, uncontrollable and traumatic stress elicits atypical diurnal cortisol patterns with high, flat diurnal profiles, i.e., a state of allostatic

load (G. E. Miller et al., 2007). When threats are constantly present, the organism might not be able to afford a diurnal rhythm in which hormonal availability decreases throughout the day. Since glucocorticoids facilitate cognitive, metabolic, and behavioral adaptations to stress (Hermans et al., 2014), persistently elevated HPA activity might be adaptive in threatening environments. However, this might only be true for temporarily limited exposure to such environments (e.g., combats). Police officers are likely to experience these high, flat diurnal profiles throughout their entire career. Since flat diurnal cortisol slopes have been shown to be the central mediator between chronic stress and poor health outcomes (Adam et al., 2017), officers might be at risk of developing serious health conditions, such as metabolic syndrome and cardiovascular diseases (Schilling, Colledge et al., 2020; Violanti et al., 2018; i.e., a state of allostatic overload). Clear signs of HPA axis dysregulation have already been identified in police officers. Compared to the general population, police officers demonstrated higher diurnal cortisol levels (Planche et al., 2019). Elevation in circulating cortisol persisted even until bedtime (Allison et al., 2019), suggesting that officers do no fully recover from occupational stress on duty before leaving the shift (also see Anderson et al., 2002). Additionally, they showed attenuated diurnal patterns and CAR (Allison et al., 2019; Charles et al., 2016; Fekedulegn et al., 2012; Violanti, Fekedulegn et al., 2017; Wirth et al., 2011). Notably, heightened cortisol levels and diurnal dysregulations were associated with both operational stressors (especially threat to the physical integrity; Allison et al., 2019; Violanti, Fekedulegn et al., 2017) and organizational stressors (i.e., lack of support and shift work; Allison et al., 2019; Charles et al., 2016; Walvekar et al., 2015). Particularly, disrupted sleep as a consequence of shift work (Gerber, Hartmann et al., 2010) has been discussed to alter HPA functioning, as night shifts have been associated with shallower daily cortisol slopes among officers (Charles et al., 2016) and lower CAR (Fekedulegn et al., 2012, 2018; Wirth et al., 2011).

Besides the negative long-term consequences of dysregulated stress systems, there is an ongoing debate whether allostatic load also influences the reactivity to acute stress, especially in high-stress populations (Heim et al., 2000; Kudielka et al., 2006; Zänkert et al., 2019). Although study results are mixed, ranging from HPA axis hyper- to hyporesponsivity in chronically stressed individuals, the few studies assessing chronic work stress in otherwise healthy populations consistently point to HPA axis hyporesponsivity (Bellingrath & Kudielka, 2016; Zänkert et al., 2019). Therefore, a time-course or two-stage model was proposed: The early state of chronic stress is characterized by hyperactivity of the HPA axis, which ultimately leads to a hyporesponsive state due to the excessive exposure to stress hormones.

In line with these considerations, results of laboratory studies hint at a hyporesponsivity of police officers to simulated police scenarios. While critical incidents, both in experimental studies (Giessing et al., 2019; Strahler & Ziegert, 2015) and on duty (Andersen et al., 2016; Anderson et al., 2002; Baldwin et al., 2019; Hickman et al., 2011), elicited pronounced psychological and cardiovascular stress responses among officers, findings on neuroendocrinal stress responses are inconsistent. Some studies observed increased sCort levels in response to simulated scenarios (Groer et al., 2010; Taverniers & de Boeck, 2014); other studies found no sCort response, although officers reported increases in self-reported anxiety (Arble et al., 2019; Giessing et al., 2019; Strahler & Ziegert, 2015). These findings suggest that the dysregulation of the HPA axis among officers might have resulted in hyporesponsivity, i.e., blunted sCort responses to critical incidents. Importantly, an acute sCort response adaptively mobilizes the body to cope with the stressor and in turn, facilitates police officers' optimal performance in critical incidents (Giessing et al., 2019; Regehr et al., 2008). Therefore, hyporesponsivity might have tremendous implications for daily police work, if blunted stress responses prevent officers from effective functioning in high-stress situations.

Together, these findings strengthen the assumption of police service as a relevant chronic stressor. As a consequence of the constant demand for stress regulation in police service, officers' basal functioning of physiological stress systems appears to be overstrained, which in turn might cause long-term risks of physical and mental disorders among police officers (Violanti, Charles et al., 2017; Violanti et al., 2018) and might impair officers' stress reactivity and performance in acute stress situations (Zänkert et al., 2019).

3.4. Hyporesponsivity in Police Officers (Manuscript 2)

Besides cross-sectional and experimental studies with their high internal validity, longitudinal field studies are needed to get insights into the interplay of acute and chronic stress responses and their underlying physiological mechanisms during daily police work. Adding to the limited literature on police officers' cardiovascular stress reactivity in real life (Anderson et al., 2002; Baldwin et al., 2019; Hickman et al., 2011), we assessed the dynamic, idiosyncratic associations of stress, mood, and physiological stress markers (i.e., sCort and sAA) of a 28-year-old male police officer over three weeks (90 data points). Four times a day (directly after waking up, 30 minutes later, 6 hours later, and before going to bed), he reported his perceived stress and mood using a smartphone application and collected saliva samples. In addition, he provided data after six subjectively experienced stressful police incidents, when

circumstances allowed sample collection without interference with his duties. In line with previous findings, we expected a dysregulated daily sCort pattern with high, flattened profiles (see Allison et al., 2019; Charles et al., 2016; Planche et al., 2019). Following the allostatic load model, we expected no sCort response in moments of acute stress despite increases in sAA and deteriorations in mood. Given the large intra-individual variability of daily life sCort assessment (Schlotz, 2019) and the novelty of ecological momentary assessment of saliva samples during police duty, we focused on increasing the number of assessment days instead of participants. Since the power of N-of-1 studies is determined by the number of repeated observations, it was possible to satisfy objectives with just one individual (Kwasnicka et al., 2019), exceeding the recommendation of 50 data points in dynamic regression modelling (McDonald et al., 2020)[2].

Our results suggest that the officer has experienced allostatic load caused by the repeated and chronic stress in police service, resulting in an inability to trigger an adaptive response to acute stressors. On average, the police officer had an overall higher sCort concentration than the general population – comparable to other frontline officers (Planche et al., 2019) –, and a rather flattened CAR (for a comparison see R. Miller et al., 2016; Wüst et al., 2000). Together, the results fit a great body of police literature on high, flattened diurnal cortisol slopes (Allison et al., 2019; Charles et al., 2016; Violanti, Fekedulegn et al., 2017; for a review see G. E. Miller et al., 2007). Supporting the assumption of a high level of general activation and arousal, daytime sAA concentrations were considerably higher than in other high-stress populations when comparing similar measurement points across studies (Strahler & Luft, 2019; Wingenfeld et al., 2010; but see Liu et al., 2017). This might be particularly critical, since daily averages of sCort, sAA, stress, and mood on off-duty days were not significantly lower compared to on-duty days (all Mann-Whitney U $p > .37$), which might hint at failure to recover (also see Allison et al., 2019; Anderson et al., 2002). Interestingly, despite elevated sAA and sCort concentrations the officer reported rather low levels of stress ($M = 2.14$, $SD = 1.16$), which is in line with other finding of medium perceived stress levels among police officers (e.g., Gerber, Hartmann et al., 2010; Schilling, Colledge et al., 2020; Schilling, Herrmann et al., 2020; see Manuscript 1).

Confirming the hypothesis on hyporesponsivity, the dynamic regression models (McDonald et al., 2020; Vieira et al., 2017) showed that sCort – but also sAA – were not related to perceived stress in daily life (sCort: $B = 0.04$ (0.10), $t(78) = 0.39$, $p = .70$; sAA: $B =$

[2] For a more detailed description of the study's materials and results see Appendix A2.

0.06 (0.13), $t(78) = 0.45$, $p = .65$) and did not increase in police incidents (Mann-Whitney U $p > .14$), which might impair police performance in high-stress situations (Giessing et al., 2019; Regehr et al., 2008). Likewise, perceived stress was associated with deterioration in calmness ($B = -0.68$ (0.10), $t(78) = -6.67$, $p < .001$), but not in valence ($B = -0.20$ (0.13), $t(78) = -0.02$, $p = .11$) and energy ($B = -0.14$ (0.13), $t(78) = -1.02$, $p = .31$). Notably, these missing psychophysiological stress responses might be explained through the lack of *very stressful* incidents (i.e., ratings ≥ 6 on the perceived stress scale ranging from 1 to 7). However, four of the six reported critical incidents rank among the most stressful operational stressors (see Chapter 2.2., Violanti et al., 2016): Two incidents required the use of force (i.e., patrolling a soccer match and arresting someone after a physical attack) and two incidents potentially involved a confrontation with injured or dead persons (i.e., car accidents).

To conclude, the results suggest police service to constitute a major stressor resulting in allostatic load with potential immediate and prolonged consequences on officers' performance, well-being, and health. We observed signs of psychological and physiological hyporesponsivity, that is attenuated stress responses, in moments of perceived stress and in response to police incidents. Given that an acute stress response adaptively mobilizes the body to cope with the stressor, the observed psychophysiological hyporesponsivity might prevent officers from effective adaptation in critical police incidents. Critically, in light of the limitations of the N-of-1 design, findings cannot be generalized – neither onto other officers nor onto other weeks of police duty. Various other influential variables on stress responses have already been identified, e.g., sleep patterns (Fekedulegn et al., 2018; Gerber, Hartmann et al., 2010), physical activity (Gerber, Kellmann et al., 2010; Gerber et al., 2014; Giessing et al., 2021; Schilling, Colledge et al., 2020; Schilling, Hermann et al., 2020), personality (Frenkel et al., 2018, 2019; Giessing et al., 2019; Landman et al., 2016), and work experience (Baldwin et al., 2019; Planche et al., 2019). Given the feasibility of ecological momentary assessment protocols in police service, future studies can test these influential variables in large-scale studies. The intense monitoring of stress functioning will advance the understanding of intra- and interindividual processes of psychological, physiological, and behavioral adaptation to police stressors.

4 Police Performance Under Acute Stress

Across the wider applied literature, it is well known that maintaining perceptual-motor performance in high-stress situations can be challenging (e.g., Hancock & Szalma, 2008).

Broadly, stress is assumed to influence perceptual-motor performance via its effect on attention, leading to less focus and higher distractibility (Eysenck et al., 2007; Nieuwenhuys & Oudejans, 2012, 2017). Although police officers are trained to respond to threats, there is little evidence that police officers are less prone to negative effects of stress on performance than other citizens (Hope, 2016). For instance, police officers achieve shooting accuracy rates of over 90% in static shooting tests, whereas shooting accuracy in stressful real-life incidents varies between 15% and 50% (Morrison & Vila, 1998). An intricate understanding about the underlying mechanisms of performance impairments under stress is an important step in the development of interventions that aim to improve police officers' performance in high-stress situations.

4.1. Performance under Stress

It is widely accepted that effective attention regulation is a key skill for peak performance. Attention is defined as a process of focusing cognitive resources on certain environmental, sensory, or cognitive information (Posner, 1980). Selective attention describes the process of focusing on task-relevant information while ignoring less relevant information (e.g., blocking out bystanders while handcuffing a suspect). Divided attention describes the distribution of attention across multiple stimuli and the simultaneous performance of two or more actions (e.g., monitoring the suspect's actions while communicating over the radio; Moore et al., 2021). While some theories argue that performance deteriorates due to heightened attention directed towards consciously controlling movements (e.g., Explicit Monitoring Theory; Beilock & Carr, 2001; Theory of Reinvestment; Masters & Maxwell, 2008), the attentional control theory (ACT; Eysenck et al., 2007) contends that performance suffers because individuals become less focused and more distractible under stress. Specifically, ACT predicts that the balance of two attentional systems is disrupted under stress, resulting in a shift from goal-directed (top-down) control to stimulus-driven (bottom-up) control. Under goal-directed control, detection and processing of information are guided by the individual's knowledge, expectations, and the current goal the individual is trying to achieve in a given situation. In contrast, under stimulus-driven control, attention is drawn by salient, threat-related stimuli (Corbetta et al., 2008). ACT suggests that stress specifically impairs the inhibition and shifting function of the central executive, while the effects on the updating function are weaker (Eysenck et al., 2007; for empirical support see Shi et al., 2019). Shifting – as positive attentional control – describes the ability to flexibly allocate attention to task-relevant cues (Miyake et al., 2000). Inhibition refers to the ability to minimize disruption

or interference from task-irrelevant stimuli, i.e., negative attentional control. Under stress, the ability to inhibit might be particularly important. In light of the increased influence of the stimulus-driven system, inhibiting interference from task-irrelevant stimuli allows the goal-directed attentional system to continue task performance with minimal disruption. Importantly, stress impairs processing efficiency (i.e., the ratio between performance effectiveness and efforts or resources spent in task performance), not necessarily performance effectiveness or quality (Eysenck et al., 2007; also see the Processing Efficiency Theory; Eysenck & Calvo, 1992). Under stress, the individual is able and highly motivated to mitigate the impairing effects of stress by using extra processing resources or mental effort in an attempt to restore or maintain goal-directed control and thus, achieve the goal in the given situation.

While ACT was initially developed to explain the effect of stress on cognitive tasks, Nieuwenhuys and Oudejans (2012, 2017) have expanded this theory to explain perceptual-motor performance under stress. They endorsed the fact that goal-directed behavior in real-life situation is not performed in isolation, but takes place in dynamic environments. Consequently, besides efficient motor control (i.e., *how* the action is performed), goal-directed behavior requires situational awareness and decision making (i.e., *which* action is performed; also see DiNota & Huhta, 2019). They conceptualized perceptual-motor performance as a parallel process in which an individual (1) perceives action possibilities in the environment (i.e., 'perception'), (2) selects the preferred action possibility (i.e., 'selection'), and (3) coordinates the execution of the movements to fulfill the action (i.e., 'action'). In this integrated model of perceptual-motor performance under stress, all of these processes are impacted by the impairing effects of stress: On the attentional level, the individual shows selective attention for threatening stimuli that are not necessarily relevant for the goal or task under stress (Bishop, 2008; Eysenck et al., 2007) and finds it harder to maintain or switch attention to other – possibly more relevant – stimuli (Fox et al., 2001). On the interpretational level, ambiguous information is more likely to be interpreted as threatening or dangerous (Bishop, 2007). Regarding the physical response, acute stress results in increased muscle tension and increased tendency to direct responses away from stressors (Coombes et al., 2009; Lang et al., 2000). Finally, borrowing from ACT (Eysenck et al., 2007), the individual is likely to spend extra mental effort in an attempt to compensate the impairing effects of stress. They propose that the extra mental effort should be invested to (1) reduce the stress response itself (e.g., through muscle relaxation or controlled respiration), (2)

inhibit stimulus-driven processing and automatic action tendencies, or (3) enforce goal-directed processing (e.g., by deliberately seeking and processing task-relevant information).

Neurophysiological stress models support these theoretical assumptions by indicating which neurochemical processes might underly these cognitive effects. When individuals are stressed, the secretion of catecholamines and glucocorticoids (see Chapter 3.1) trigger a dynamic adaptation of large-scale brain networks enabling an adaptive reallocation of resources according to the cognitive demands (Hermans et al., 2014). Specifically, the activity in the neurocognitive salience network is increased. At the same time, the executive control network needed for endogenous attention and higher-order cognitive control is suppressed (Hermans et al., 2014). Combined with a lower excitation threshold in the cortico-spinal tract (Gökdemir et al., 2018; Hajcak et al., 2007; Oliveri et al., 2003; Schutter et al., 2008; van Loon et al., 2010), these neurophysiological changes promote attentional vigilance for potential threats and increased action readiness. As a result, fast stimulus-driven responses are facilitated at the cost of goal-directed control (Bishop, 2008; Hermans et al., 2014; Schwabe & Wolf, 2011), as proposed by ACT.

4.2. Performance Decrements in Police Service

The discrepancy in performance observed in real-life critical incidents compared to training (e.g., Morrison & Vila, 1998) has motivated researchers to investigate officers' performance decrements in occupational performance under stress. Over the past years, a large body of literature has accumulated showing that high-stress police scenarios resulted in impairments of shooting performance (Giessing et al., 2019; Landman et al., 2016; Nieuwenhuys & Oudejans, 2010; Taverniers & De Boeck, 2014), quality of skill execution (Bertilsson et al., 2019; Renden et al., 2014; Renden, Landman et al., 2017; Nieuwenhuys et al., 2009, 2017), proportionality of applied force (Nieuwenhuys, Cañal-Bruland & Oudejans, 2012; Renden, Landman et al., 2017), memory (Hope, 2016; Hope et al., 2016), and communication skills (Arble et al., 2019; Renden, Landman et al., 2017). In line with ACT and the integrated model for perceptual-motor performance (Nieuwenhuys & Oudejans, 2012, 2017), a series of studies suggest that the stress-induced performance decrements among police officers can be explained by a shift to stimulus-driven control resulting in changes in perception (Nieuwenhuys & Oudejans, 2010, 2011), selection (Correll et al., 2002; Nieuwenhuys, Cañal-Bruland & Oudejans, 2012; Nieuwenhuys, Savelsbergh & Oudejans, 2012; Payne, 2001), and action (Nieuwenhuys & Oudejans, 2010; Renden et al., 2014, Renden, Landman et al., 2017).

A particularly critical skill in police service is to make shoot/don't shoot decisions in split seconds (e.g., Davies, 2015; Hamilton et al., 2019). In cognitive psychology, this skill refers to response inhibition and is commonly investigated in Go/NoGo tasks or stop-signal tasks[3]. In line with ACT (Eysenck et al., 2007, for a meta-analysis see Shi et al., 2019), response inhibition in shooting tasks has been shown to be impaired under stress. In these video-based shooting tasks, officers were instructed to decide whether to shoot at an opponent who rapidly appear either with a gun (Go response) or a phone (NoGo response). Typically, experimental manipulations of stress resulted in biases towards shooting. That is, shooting responses became faster and the percentage of unarmed opponents that was accidentally shot at (i.e., false alarms) increased (Hashemi et al., 2019; Nieuwenhuys, Savelsbergh, & Oudejans, 2012; Nieuwenhuys et al., 2015; but see Gladwin et al., 2016). In a recent study, the shooting task was extended by trials with a stop signal, which instructed the participants to cancel the ongoing response (i.e., the opponent puts down the gun; van Peer et al., 2019). Results of the Stop trials indicated that stress impaired the ability to inhibit the shooting response to the surrendering suspect (van Peer et al., 2019). However, contradicting previous research (Nieuwenhuys, Savelsbergh, & Oudejans, 2012; Nieuwenhuys et al., 2015), stress did not increase the percentage of false alarms. The authors argued that this discrepancy might be explained by a methodological difference in the stress manipulation. They employed a performance-contingent manipulation in which incorrect responses were followed by a negative (aversive) stimulus (e.g., Hashemi et al., 2019; van Peer et al., 2019), whereas in earlier studies, stressors were unrelated to the task (e.g., Nieuwenhuys, Savelsbergh, & Oudejans, 2012; Nieuwenhuys et al., 2015). In an attempt to avoid the negative stimuli, participants might have tried harder to maintain performance even under high stress, preventing decision accuracy from deteriorating under stress. Together, these findings indicate that stress increases the tendency to respond quickly and impairs the ability to inhibit prepotent responses, but does not impair the ability to withhold erroneous responses when performance-contingent stressors motivate participants to perform well (van Peer et al., 2019).

[3] Various task paradigms are used to investigate response inhibition in the laboratory, with Go/NoGo tasks (Donders, 1868/1969) and stop-signal tasks (Lappin & Erikssen, 1966) being the most common. In the former, participants are required to respond to Go stimuli as quickly as possible and withhold their responses to other stimuli (NoGo). In the latter, the Go stimuli is occasionally followed by a stop signal after a variable delay) indicating that the initiated Go response should be withheld. Based on the independent horse race model (Logan & Cowan, 1984), stop-signal tasks allow the calculation of the stop signal reaction time (SSRT, see e.g., Logan 1994) as a measure for the time it takes the participant to complete the inhibitory process after the appearance of the stop signal. Among the stop-signal paradigms, the anticipatory response inhibition (ARI) task (He et al., 2021) provides the most reliable measure of response inhibition, as the Go response is time-locked in anticipation of a cue reaching a target which prevents participant from strategic slowing (Leunissen et al., 2017).

4.3. Response Inhibition under Physical and Emotional Stress (Manuscript 3)

Critically, the maintenance of performance under stress also depends on the availability of energetic resources (Nieuwenhuys & Oudejans, 2017). Limited energetic resources due to preceding activity, various stressors at the same time, or limited recovery might affect the stress-performance relationship. For example, depletion of mental resources as a result of preceding cognitive activity resulted in impaired attention regulation (i.e., shorter fixations on target, greater distraction by worrisome thoughts; Englert, 2017; Englert & Betrams, 2012, 2015; Englert, Betrams et al., 2015, Englert, Zwemmer et al., 2015). In police service, officers typically need to respond to critical incidents that are both emotionally and physically demanding (e.g., during the night shift with little sleep or after a physically effortful chase of the suspect). In addition to the emotional stressors (see Chapter 2.2), research clearly demonstrates that police officers encounter many sources of physical stress, e.g., standing, climbing stairs or other objects, squatting/kneeling, pulling/pushing, or running (Anderson et al., 2002). Similar to emotional stress, physical effort above the ventilatory threshold or for extended durations can be considered an acute stressor that disrupts bodily homeostasis and elicits neurophysiological changes. Specifically, neural resources from the frontal cortex are reallocated to the reticular-activating system (Dietrich & Audiffren, 2011). While the activation process facilitates fast, stimulus-driven responses in reaction time tasks (Audiffren et al., 2008; Davranche & Audiffren, 2004; Davranche et al., 2005, 2006), hypofrontality (i.e., downregulation of the prefrontal cortex) can explain performance decrements in tasks relying on executive control under physical stress (e.g., Audiffren et al., 2009; Dietrich & Sparling, 2004; Eddy et al., 2015; Mahoney et al., 2007). On an attentional level, the parallel processing model predicts that under high intensity of physical stress, attention becomes increasingly focused on bodily cues at the expense of attention resources available for external task performance (Hutchinson & Tenenbaum, 2007; Rejeski, 1985).

Although police officers face emotional and physical stressor simultaneously, so far, research has focused on their isolated effects. An intricate understanding about how emotional and physical stressors together influence performance is currently lacking. Given the importance of the ability to inhibit prepotent responses for goal-directed behavior in dynamic settings, we were interested in the effects of emotional and physical stress on response inhibition. Since theoretical approaches for both emotional and physical stress point towards stimulus-driven control at the expense of goal-directed control under stress, we predicted impaired response inhibition under emotionally and physically stressful circumstances,

respectively (Eysenck et al., 2007 for emotional stress; Dietrich & Audiffren, 2011; Hutchinson & Tenenbaum, 2007 for physical stress). Regarding the interaction effect, we assumed that one stressor would "cancel out" the other, with the direction of the effect being unclear. On the one hand, levels of emotional stress may be reduced under high physical stress because the associative focus on physiological sensations may limit the capacity to process threat-related information (Hutchinson & Tenenbaum, 2007; Tenenbaum, 2001). On the other hand, high emotional stress may cancel out the potential effects of physical stress because the threat-related attention focus may limit processing capacity for the physiological sensations resulting from physical stress (Eysenck et al., 2007; Nieuwenhuys & Oudejans, 2012, 2017). Ultimately, we assumed that the direction of the effect would depend on the relative intensity of either stressor (Sebastian et al., 2020)[4].

Initial results from a Go/NoGo task suggest that response inhibition can be maintained under both emotionally and physically demanding conditions (Cantelon et al., 2019). Under low emotional stress, task performance decreased (i.e., false alarms increased) with increasing physical stress. Under high emotional stress, task performance improved (i.e., false alarms decreased) with increasing physical stress. This finding suggests that high emotional stress may have cancelled out potential negative effects of physical stress on response inhibition. Critically, several limitations in the experimental set-up might threaten the validity of these findings: The Go/NoGo task yields no true measure of response inhibition (Verbruggen & Logan, 2008), the manipulation of emotional stress was unrelated to the task (i.e., not performance contingent), and the manipulation of physical stress was time-confounded. Addressing these shortcomings, we examined response inhibition in a stop-signal task in a full-panel within-subject experimental design with a performance-contingent manipulation of emotional stress. Based on an a-priori power analysis (repeated measures ANOVA, 80% power, $f = .25$, $\alpha = .05$; Cantelon et al., 2019), 24 students of the University of Auckland performed an anticipatory stop-signal task (Leunissen et al., 2017), whilst cycling for 2 x 30 minutes at light (60% HR_{max}) and vigorous intensity (86% HR_{max}) on a stationary bicycle ergometer. To manipulate emotional stress, participants either received a mild (90mA, 200µs, single-pulse) electric shock over the biceps brachii (high threat) or no shock (low threat) upon making a task error. In an anticipatory response inhibition task (He et al., 2021), participants responded to a rising indicator on a screen, using a switch mounted on the bicycle handlebar. They were either instructed to lift their finger off the switch as soon as the indicator reached a

[4] The hypotheses for the current study were preregistered before data collection, see https://osf.io/rndy2.

target line (i.e., Go trials; 70% of trials) or to inhibit their lifting response if the indicator automatically stopped rising before the target line (i.e., Stop trials; 30% of trials). In contrast to the Go/NoGo task, the anticipatory response inhibition task provides a pure measure of the latency of response inhibition, with shorter stop signal reaction times (SSRTs) indicating superior inhibitory performance (Logan, 1994; Logan & Cowan, 1984)[5].

Heart rate (HR) data, self-reported anxiety scores and perceived exertion levels showed that both manipulations successfully induced physical and emotional stress, respectively. The linear mixed effects models showed that self-reported anxiety increased under threat versus safe conditions (b = 0.64 (0.12), $t(23.01) = 5.45$, $p < .001$, $BF_{10} = 1.23 \times 10^4$). Perceived exertion increased under vigorous versus light exercise intensity (b = 2.36 (0.19), $t(23.00) = 12.57$, $p < .001$, $BF_{10} = 1.96 \times 10^9$). HR increased under threat (b = 0.68 (0.19), $t(23.09) = 3.69$, $p = .001$, $BF_{10} = 56.12$) and vigorous intensity (b = 22.20 (1.02), $t(23.00) = 21.78$, $p < .001$, $BF_{10} = 1.33 \times 10^{14}$). However, our assumptions of impaired response inhibition under physical and emotional stress were not supported by our data. Our results did not show any main or interaction effects of emotional and physical stress on response times in Go trials (all $p > .073$) and on SSRTs in Stop trials (all $p > .509$).

While these findings contradict our theoretical predictions on neurophysiological (Dietrich & Audiffren, 2011; Hermans et al., 2014) and attentional changes under stress (Eysenck et al., 2007; Rejeski, 1985; Tenenbaum, 2001), they add to a sparse or at best inconclusive body of literature on the influence of emotional and physical stress on response inhibition. Concerning the effect of physical stress, meta-analytic findings suggest impairments of cognitive task performance during high-intensity exercise (Chang et al., 2012; Lambourne & Tomporowski, 2010). However, most of the included studies investigated cognitive inhibition (e.g., in Eriksen's Flanker Task, Stroop Task; see Ludyga et al., 2016) rather than response inhibition (for exemptions see Chu et al., 2015; Joyce et al., 2009)[6]. Critically, since cognitive inhibition and response inhibition recruit distinct neural processes and systems (Aron, 2007; Friedman & Miyake, 2004), they may be differentially affected by physical stress (for a similar argument relating to emotional stress see Roos, Knight, Beauchamp, Giuliano et al., 2017; Shields et al., 2016). Concerning the effect of emotional stress, research suggests that response inhibition may either be enhanced (Senderecka, 2016;

[5] For a more detailed description of the study's materials and results see Appendix A3. All materials, raw data, and code for analysis are available online at https://osf.io/wdtz7/.
[6] Importantly, these studies investigated the effects of physical stress on response inhibition after, not during the exercise.

Robinson et al., 2013; Weinbach et al., 2015) or impaired (Herbert & Sütterlin, 2011; Kalanthroff et al., 2013; Pessoa et al., 2012, Experiment 2; Rebetez et al., 2015; Roxburgh et al., 2019; van Peer et al., 2019; Verbruggen & de Houwer, 2007), depending on the stressor manipulation (performance-contingent vs. task-irrelevant; van Peer et al., 2019) and stressor intensity[7]. Indeed, a recent study highlighted the importance of the subjective threat perception for an effect of emotional stress on response inhibition (Sebastian et al., 2020): Only highly anxious participants showed impaired response inhibition to high stress, while less anxious participants improved their performance. Although self-reported anxiety was higher under high compared to low threat, values were rather low compared to previous studies which employed shooting tasks with gun stimuli (e.g., Nieuwenhuys, Savelsbergh, & Oudejans, 2012; Nieuwenhuys et al., 2015). In addition, vigorous exercise might have triggered subjective responses (e.g., perceived exertion) that functioned as emotional stressors themselves (e.g., Hall et al., 2002; Raglin & Wilson, 1996), as indicated by elevated self-reported anxiety levels under low-threat conditions. Potentially, the anxiety-inducing effect of vigorous exercise reduced the relative difference between the emotional stress conditions and thus, concealed the main and interaction effects on task performance.

To conclude, our findings suggest that response inhibition, as measured in an ARI task, is robust against mild levels of task-relevant emotional stress and against effects of high physical stress in the form of concurrent vigorous exercise intensity. As a consequence of the rather low anxiety scores, participants might have still been able to effectively invest extra mental effort as a compensatory mechanism to mitigate the detrimental effects of stress (Eysenck et al., 2007; Nieuwenhuys & Oudejans, 2012, 2017) in an attempt to maintain their response and inhibitory task performance. Critically, the sample of the present study consisted of healthy university students, not police officers. Given the preliminary evidence on officers' hyporesponsivity to acute stressors (see Manuscript 2; in line with Giessing et al., 2019; Strahler & Ziegert, 2015) and their past experiences with high-stress situations (see Manuscript 1), studies with police samples might yield different results and generalization of the present results to police samples need to be treated with caution.

4.4. Maintaining Performance Under Stress

On duty, police officers manage to solve most of the high-stress situations professionally. Likewise, not all studies found performance decrements under stress among

[7] For a more in-depth discussion of possible moderators see Roos, Knight, Beauchamp, Giuliano et al., 2017 and Shields et al., 2016.

officers (e.g., Giessing et al., 2019; Regehr et al., 2008). These findings – in line with the results described in Manuscript 3 – suggest that officers can indeed overcome the negative effects of stress on performance. Police officers often report that they have invested more mental effort in high-stress compared to low-stress tasks (Giessing et al., 2019; Nieuwenhuys & Oudejans, 2010, 2011; Nieuwenhuys et al., 2009; Renden et al., 2014). Given that some officers could maintain or improve performance and others did not, it has also become clear that merely spending more mental effort is not always sufficient. In fact, it is crucial how extra mental effort is invested (Nieuwenhuys & Oudejans, 2012, 2017). Initial support for the mental effort strategies proposed in the integrated model (see Chapter 4.1) stems from intervention studies aimed at increasing police officers' performance under stress, such as attention (Vine et al., 2014), visualization (Colin et al., 2014), or inhibition training (Ducroq et al., 2016) – often with positive effects on performance. However, there is a growing body of literature suggesting that extra mental effort should not be spent in an attempt to reduce stress responses (e.g., Giessing et al., 2019; Landman et al., 2016; Moore et al., 2021). In a shooting task, highly self-controlled police officers could maintain shooting performance, despite experiencing increased anxiety (Landman et al., 2016). In contrast, when highly self-controlled officers successfully reduced anxiety, self-control was negatively associated with shooting performance (Giessing et al., 2019). Arguably, attempting to suppress or change the unwanted stress sensations might be counter-productive as it may lead to a decrease in goal-directed focus on the task. Although these findings are still preliminary, they can be aligned with mindfulness and acceptance approaches (also see Moore et al., 2021). In mindfulness and acceptance approaches, individuals learn to sustain task-focused, goal-directed attention by training open, non-reactive, and present-moment awareness (Kabat-Zinn, 1990), which enables them to experience and accept unpleasant stress sensations without acting on them (Hayes, 2016; Harris, 2009). In contrast, the unwillingness to experience negative thoughts, emotions, and bodily sensations is assumed to result in avoidance behavior and thus, performance decrements (Hayes et al., 2004; for the implementation of this idea in high-stress domains see Frenkel et al., 2019; Krupop et al., 2021). Together with the finding that response inhibition is robust against (mild) emotional and physical stress (see Manuscript 3), it seems that extra mental effort should be directed at either goal-directed processing or inhibiting stimulus-driven responses rather than reducing the stress response itself. Hence, interventions aimed at improving performance in dynamic high-stress police incidents should teach officers mechanisms or *coping strategies* to effectively invest mental effort in the enforcement of goal-directed control or in the inhibition of stimulus-driven responses. One possible

intervention which has been shown to effectively improve performance in high-stress situations is training under stress (Kent et al., 2018; Oudejans, 2008; Nieuwenhuys & Oudejans, 2010, 2011; for a meta-analysis see Low et al., 2021). In the following chapter, I argue that a constraints-led approach (Davids et al., 2008) can help to design representative police scenarios in which police officers can learn how to spend extra mental effort and improve their performance under stress.

5 Police Training Under Stress

Given the nature of police work (see Chapter 2.2), it is impossible to prepare officers for all stressors they might encounter on duty. Therefore, it is critical that police officers familiarize with the presence of psychophysiological stress responses and their influence on performance. Officers should become independent, creative problem solvers in dynamic and complex environments even when experiencing elevated stress levels (Arble & Arnetz, 2021; Blumberg et al., 2019; Staller & Zaiser, 2015). Following the considerations of the integrated model (Nieuwenhuys & Oudejans, 2012, 2017), police officers need to learn coping strategies which allow them to effectively invest extra mental effort in order to mitigate the negative effects of stress on perception, selection, and action. Although stress management programs have been offered in lecture- or workshop-based courses in police service (e.g., relaxation techniques, mindfulness; Arble & Arnetz, 2020), police officers are reluctant to make use of such programs (Wester et al., 2010). In addition, officers may experience difficulties in translating the psychological principles into something practical that can actually be applied in everyday police work (Papazoglou & Andersen, 2014; Papazoglou et al., 2020). Even though psychoeducation and declarative knowledge about stress and performance may certainly be an additional benefit, it is more desirable to teach officers how to apply psychological principles of stress and performance *while* engaging and interacting in stressful environments (Brammer et al., 2021; Papazoglou & Andersen, 2014; Papazoglou et al., 2020). During the COVID-19 pandemic, police officers highlighted scenario-based training as an important coping resource in which they have acquired occupationally relevant skills that helped them to cope in novel situations during police service. To make sure that learning indeed transfers to critical incidents on duty, police training should replicate the performance environments as closely as possible. In representative learning environments, police officers experience psychophysiological stress responses and their effects, can develop and try out effective coping strategies, and integrate their verbal, physical, cognitive, and psychological

skills to solve the situation (Arble & Arnetz, 2021; Bennell, Blaskovits et al., 2021; Di Nota & Huhta, 2019).

5.1. Constraints-led approach for Police Training Under Stress (Manuscript 4)

The integrated process of accurate perception, selection, and action is considered as a key asset of expert performance in perceptual-motor tasks (Nieuwenhuys & Oudejans, 2012, 2017) Similarly, the ecological dynamics framework suggests that cognition, perception, and action are deeply intertwined and together regulate functional behavior to satisfy key constraints (Seifert et al., 2017). These key constraints include specific task demands, the environmental structure and physics, the biomechanics of each individual's body, and perceptual information about informational variables (Davids et al., 2008). Functional behavior – in the sense of behaviors that support achieving intended task goals during performance – emerges from the dynamic interaction between the individual's action capabilities and opportunities or invitations for action (i.e., *affordances*; Gibson, 1979) offered by the environment. In this sense, expert performance in perceptual-motor tasks is defined as the individual's capacity to functionally adapt the movements to the dynamics of complex performance environments by continuously perceiving information about affordances and making decision in accordance with goal-directed task intentions (Davids et al., 2015).

Within this framework, skill learning refers to the process of adapting and attuning to the environment and its constraints (Davids et al., 2013). The constraints-led approach (CLA; Davids et al., 2008) translates the theoretical key assumptions of the ecological dynamic frameworks into guiding principles for the process of motor skill acquisition. Broadly, the CLA articulates that the trainee will learn to self-organize perception, cognition, and action in an attempt to generate functional movement solutions when confronted with the interaction of different constraints (i.e., individual, environmental, and task constraints). *Individual constraints* refer to all individual prerequisites, including relatively permanent or variable physical, motivational, emotional, and cognitive states. *Environmental constraints* include variable (e.g., temperature, light conditions, soil conditions) and stable ambient conditions (e.g., gravity). *Task constraints* include the specific factual and operational structure of the task at hand. In dealing with these constraints in the learning environment, the trainee learns to discover affordances and to align them with their own action capabilities. Following the concept of *degeneracy*, one central assumption proposes that functionally equivalent actions can be achieved by structurally different movements. Therefore, one should not pursue one

optimal pattern of coordination. Instead training should be concerned with the process of aligning task, environmental, and individual constraints. In other words, the trainee is explicitly encouraged to explore individualized problem solutions to achieve the desired outcome. Given the influence of even the smallest changes in the environment (e.g., darkness, limited space, position), variability and flexibility in problem solving, alongside individualized movement patterns, are considered functional for performance (Davids et al., 2008).

Importantly, training should aim to generate valid physical, perceptual-cognitive, and affective representations of the performance environment (Davids et al., 2013). Crucial to the selection of these constraints for the learning environment is the principle of *representativeness* (Pinder et al., 2011). That is, constraints in the learning environment achieve similar probabilities of occurrence as they do in the performance environment (Brunswik, 1956; Pinder et al., 2011). As a result, the representative learning design fulfills the principle of functionality of perceptual information and action fidelity. *Functionality of perceptual information* enables trainees to adapt to information sources (and affordances) that are representative of the performance environments. *Action fidelity* is high when the trainee's movement responses in the simulated training environment equal the movement responses the trainee would show in the performance environment (Pinder et al., 2011).

However, so far, police training has focused on the rehearsal of assumingly optimal physical, technical, and tactical skills, often neglecting the effects of stress (Blumberg et al., 2019). To ensure valid (affective) representations of critical police incidents in training, stress-inducing constraints should be integrated into the learning environment and thus, facilitate transferability of learning outcomes into high-stress-situations (Körner & Staller, 2018). In dealing with the stress-inducing constraints during training, the officer experiences the psychophysiological stress responses related to the specific task, and their impact on cognitive and motor performance (i.e., functionality). Using effective coping strategies to maintain goal-directed control and/or suppress stimulus-driven responses under stress (see Chapter 4.4; Nieuwenhuys & Oudejans, 2012, 2017) then becomes part of functional problem solving (i.e., action fidelity; Körner & Staller, 2018).

In the literature, training interventions that focus on the manipulation of affective constraints (Headrick et al., 2015) are known as training under stress or pressure training. Although training under stress might not be able to perfectly replicate real-life stress situations, it has been shown to enhance performance delivery in various high-stress domains (Gröpel & Mesagno, 2017; Kent et al., 2018; Low et al., 2021), including law enforcement

(Nieuwenhuys and Oudejans, 2010, 2011; Oudejans, 2008). Interestingly, training under stress did not necessarily reduced stress responses. Rather, it seemed to improve the utilization of mental effort when officers experienced elevated stress responses (Nieuwenhuys & Oudejans, 2011; Oudejans & Pijpers, 2009, 2010)[8].

Recently, Körner et al. (2021) were the first to evaluate the efficacy of a training intervention following CLA compared to traditional police training practices. Although they did not specifically focus on the manipulation of stress, it is likely that the constraints implemented in the training of knife attacks (e.g., confined space, number of attackers, starting position) also influenced trainees' psychophysiological stress state. Results showed that both groups benefitted from the training intervention, but the CLA group demonstrated better performance and higher problem-solving ability after the intervention (i.e., participants in the CLA group were hit less and solved the attack faster and more often). However, the CLA group expressed considerable uncertainties after the training. These uncertainties resulted from the lack of declarative knowledge about an ideal technical solution. Along with the desire for an ideal technique, the CLA group expressed their need for more demonstrations by the trainer, repetition of isolated technique, and direct verbal feedback (Körner et al., 2021). Hence, police training seems to require a conceptual and situational trade-off between the subjective need of trainees for conscious knowledge about ideal techniques to strengthen perceived coping resources (see Manuscript 1) and the need to robustly adapt to the constraints of the field (see Manuscript 4).

5.2. Putting Theory into Practice: Pandemic-Specific Police Training (Manuscript 5)

There is little empirical evidence available on the extent to which police training generally meets its objectives. Recent studies (Renden et al., 2015; Staller, Körner, Heil, Abraham, & Poolton, 2021) point to a lack of transfer between training and field due to too little time spent on learning (Staller, Körner, Heil, Klemmer et al., 2021), the content taught (Renden, Savelsbergh et al., 2017) or pedagogical aspects of the training design (Körner et al., 2021). Consequently, as a first principle, researchers frequently demand that "police training should embrace an evidence-based philosophy" (Arble & Arnetz, 2021, p. 232; also see Anderson et al., 2019; Di Nota & Huhta, 2019; Di Nota et al., 2021; Jenkins et al., 2021; Körner et al., 2021). In its most basic sense, evidence-based practice requires police training to implement concepts that have been empirically proven to be effective (Arble & Arnetz,

[8] For an overview of principles for training under stress in police training see Table 1 of Manuscript 4 in Appendix A4.

2021). Acknowledging that training under stress has been shown to improve performance in high-stress situations (Körner et al., 2021; Low et al., 2021), the question is not whether police training should implement training under stress, but how to implement it most effectively (see Commentary #2 by Arne Nieuwenhuys in Bennell, Alpert et al., 2021).

Currently, scenario-based training is considered the gold-standard for complex motor learning (Di Nota & Huhta, 2019). In scenario-based training, various types of critical incidents are simulated in real or artificially constructed environments, props, sounds, and lighting with the help of professional role players. According to the Event-Based Approach to Training (Fowlkes et al., 1998), these scenarios should include trigger events which provide officers an opportunity to demonstrate the essential skills defined in the training objectives (Jenkins et al., 2021; Nguyen et al., 2016). Following the representative learning design (Headrick et al., 2015; Pinder et al., 2011), the trigger events and its constraints should map onto what officers experience in the field (see Chapter 5.1). Ideally, this is a data-driven process in which systematic and representative data from real-life critical incidents is used to identify (1) effective skills that are most commonly used in the field, (2) trigger events in which these skills are needed, and (3) stress-inducing individual, environmental, and task constraints impeding the execution of the required skill (Jenkins et al., 2021).

Following this procedure, in Manuscript 4, we provided an example of how scientific findings on police officers' perceived stressors (during the COVID-19 pandemic) can be used for scenario-building in police training. Police officers' reports have confirmed scenario-based training as an important coping resource to cope with pandemic-specific stressors (see Manuscript 1; Chapter 2.3). Specifically, police officers mentioned 1) the automatism of keeping distance as a mean of self-protection, (2) target-oriented communication, especially with upset, anxious or mentally unstable individuals, (3) the ability to make quick decisions, and (4) stress regulation in critical situations as the most useful skills. As such, these skills should constitute the training objectives for pandemic-specific scenario training. To identify relevant trigger events for these skills, we re-analyzed the police officers' reports on work stressors (Manuscript 1). Interestingly, the possible trigger events encompassed both unprecedented scenarios and familiar scenarios in which procedures or regulations have changed due to the COVID-19 pandemic. Examples for unprecedented scenarios included the enforcement of restrictions on common behaviors (e.g., controlling quarantine, disbanding of small groups, banning civilians from public spaces), spitting attacks as hazardous behavior of assailants, and navigating through larger groups (potentially during riots) while maintaining physical distance. In familiar scenarios, such as domestic violence, identity checks, or vehicle

controls, the integration of novel pandemic-specific constraints has impeded the common skill execution and therefore, required the refinement of functional behaviors. Following CLA, pandemic-specific training will benefit from the integration of stress-inducing constraints in both unprecedented and familiar scenarios to encourage trainees to adapt to the novel demands. An overview of concrete examples for stress-inducing constraints in pandemic-specific scenarios can be found in Table 1[9].

Constituting a promising example for evidence-based police training, the analyses demonstrated how scientific insights can inform, update, and improve current police training practices and scenario-building. Nevertheless, it must be acknowledged that the underlying data is subjective in nature and therefore, might be biased, jeopardizing the principle of representativeness (see Section 5.1). Ideally, the self-reported data is supplemented with objective statistics about the frequency of call types (e.g., domestic disturbances, mental health calls), information about situational factors (e.g., lighting, indoors/outdoors, around vehicles), individual characteristics of the involved persons (e.g., intoxication), and, if applicable, use of force interventions applied (e.g., pepper spray). This approach would enable police trainers to incorporate a wide range of representative constraints that are approximately proportional to what officers experience on duty.

Table 1

Stress-inducing Constraints for Pandemic-Specific Police Training Scenarios

Constraints	What can be manipulated?	Example
Task	Type of police intervention Situation-specific demands	Current legal regulations Novel service procedures
Individual	Physical, emotional, and cognitive states	Increased (perceived) risk of infection (e.g., due to advance information via radio, visible symptoms) Limited recovery due to multiple operations
Environment	Access to perceptible information Physical properties of the environment	Confined space Personal protection equipment

[9] For a more detailed description of the study's results see Appendix A5.

5.3. The Potential of Virtual Reality for Police Training Under Stress (Manuscript 4)

Although scenario-based training is widely used in police academies (Di Nota & Huhta, 2019), it is limited by its resource intensity, restricted variability in the scenario set-up, and few feedback options (see Manuscript 4). In search of safe, immersive, variable, and cost-effective training tools, the technology of virtual reality (VR) has attracted the interest by police agencies, research groups, and technology companies (e.g., Europeans Union's Horizon 2020 project SHOTPROS, grant No. 833672, https://shotpros.eu). VR simulates an artificial three-dimensional environment in which the individual can move, act, and interact with objects and persons. Through head-mounted displays or specially designed rooms with multiple large screens, VR generates realistic images, sounds, and haptic feedback that give the individual the feeling of being physically present in the virtual environment. By sensors that detect movements, the individual can interact with and react to the virtual environment.

Despite the growing number of law enforcement agencies investing in VR systems for police training, limited scientific evidence informs and justifies its application. Specifically, it is unclear whether skills acquired in VR transfer to real-life behavior, whether VR develops skills beyond the existing training practices, and how its effectiveness compares to other training practices (see Stone et al., 2019). Hence, a solid theoretical framework is needed to rationalize the implementation of VR systems in police training and to guide the development of effective and efficient learning designs within VR (Stone et al., 2019). Building on the considerations of CLA, VR training needs to satisfy the two critical features of a representative learning design (Pinder et al., 2011, see Chapter 5.1). That is, VR technology and related devices should display representative information (functionality) and encourage active engagement of the trainee in the simulated environment (action fidelity). In other words, training in VR should give the trainee the opportunity to perceive relevant information and utilize different affordances, so that the trainee is required to regulate actions to achieve specific task goals (Stone et al., 2019). To check whether these theoretical requirements can be met, I conducted a literature-based analysis of the strengths, weaknesses, opportunities, and threats (SWOT) associated with the use of VR in police training. Originally, the SWOT framework as an instrument of strategic planning was developed to analyze the position of companies in a specific market field. In academia, it can be utilized to critically analyze the application of emerging technologies in a specific field (e.g., Düking et al., 2018; Engelbrecht et al., 2019).

To summarize the results[10], VR offers the strength of high functionality of perceptual and affective information due to its high control over the perceptual information presented, whereas action fidelity is currently threatened due to the limited interaction possibilities. By virtue of its nature, VR enables the design of an almost infinite number of complex and potentially dangerous scenarios that would be difficult or impossible to simulate in the real world for financial, time, personnel, or ethical reasons (Düking et al., 2018; Engelbrecht et al., 2019; Murtinger et al., 2021). Given the high control over the training procedures (e.g., order of events, level of complexity, reduction of risks), a great variability of scenarios and permutations of representative constraints can be configured and systematically manipulated (see Chapter 5.1; for a practical implementation see Caserman et al., 2018). As such, learning opportunities can be individualized for each trainee, allowing the refinement of various functional problem solutions. Typically, traditional scenario-based training cannot provide the full (visual) context that officers need to adequately assess the situation. Critical context constraints are often verbally described, potentially giving away the learning experience of perceiving these constraints as an affordance (see Haskins et al., 2020). VR can overcome such issues by simulating very detailed visual and audio contexts containing both explicit and subtle constraints and affordances. Given the importance of an efficient visual search rate, enhanced selective attention allocation, extended visual span, and scan pattern systematicity for expert performance (Brams et al., 2019; Heusler & Sutter, 2019), (visual) cues and sight lines simulated in VR can guide attention processes and make affordances in the environment more explicit. For instance, salient cues appearing in areas of interest might help the trainee to gather relevant information and utilize affordances (Craig, 2014). Thus, VR can help to optimize information processing of task-relevant stimuli and ignoring irrelevant stimuli, which is especially relevant for goal-directed behavior in stressful environments (Nieuwenhuys & Oudejans, 2012, 2017). Importantly, a representative training environment does not only accurately portray the perceptual information of the performance environment, but also stimulates the corresponding psychophysiological (stress) responses (Headrick et al., 2015; see Chapter 5.1). Confirming the affective functionality of VR, research in high-stress domains (i.e., police and sports) has shown that audio-visual manipulations in virtual environments have successfully induced stress and corresponding psychophysiological responses (Argelaguet Sanz et al., 2015; Groer et al., 2010, Muñoz et al., 2020; Stinson & Bowman, 2014). Nevertheless, continual development of technology to improve frame rate,

[10] For a detailed description of the results see Appendix A4.

tracking, field of view, refresh rate, latency, and resolution can increase immersion and presence in VR environments (Cummings & Bailenson, 2016), increasing the functionality of perceptual and affective information in VR.

Critically, to fully utilize this potential of functionality, it is important to allow for a variety of realistic behavioral responses (i.e., action fidelity) ranging from personal communication, physical self-defense skills, and pepper spray to firearms. A weakness of the current training is that certain training methods prime the use of guns even before the training scenario has started (e.g., color ammunition training with full body protection equipment). The expectations about the upcoming gun use in the scenario might change which affordances the trainee perceives and utilizes in the learning environment, potentially resulting in decreased action fidelity. To preserve action fidelity, VR training should enable the use of a wide range of operational equipment by developing physical replicas and haptics of the virtual counterparts (for a recent development of a tactical belt see Murtinger et al., 2021). Nevertheless, the potential development of unnatural motion patterns (e.g., in the shooting technique) due to the obtrusiveness of the VR equipment still imposes a threat to the action fidelity (Stone et al., 2019; Düking et al., 2018). Besides the use of force, police interventions usually require a high degree of communication, either on radio, with colleagues, with bystanders, or with opponents. In the applied practice of VR, the delayed responses as well as the lack of verbal interaction and facial feedback by computerized avatars constitute an additional threat to the action fidelity, especially in situations requiring social interactions.

In conclusion, VR has the potential to supplement and enrich current training practices, as individualized training scenarios can enhance context-dependent decision-making and facilitate the development of creative problem solutions (also see Stone et al., 2019). However, future developmental efforts are needed to increase the number of representative action possibilities to achieve action fidelity in VR. Despite VR still being a growing technology and the lack of empirical support for its effectiveness, police-specific VR solutions are already on the market (for an overview see SHOTPROS, 2020). As law enforcement agencies have already started to implement VR in their training curricula, it is crucial to design systems that meet the specific training principles and support the desired didactical approach. Defining evidence-based requirements and practical guidelines will help law enforcement agencies to successfully integrate VR in their current training curricula (see Giessing & Frenkel, in press; Murtinger et al., 2021). Close collaborations among law enforcement agencies, technology companies, and research institutions can help to identify and meet needs for further technological and scientific developments of VR training.

Ultimately, research should deliver the much-needed evaluations of VR efficacy and its transferability to real-life behavior (for a detailed discussion on future directions see Chapter 6.3).

6 General Discussion

This dissertation focused on the psychological and physiological stress processes among police officers and their impact on performance in police service including critical incidents and police training. Following a holistic approach, research lines in the cognitive, biological, and ecological psychology on police stressors, perceptual-motor performance under stress, and training under stress were integrated. By employing a multi-theory and multi-method approach, it was possible to identify crucial interplays within the complex nature of stress processes in police service. The dissertation drew on the cognitive appraisal theory (Lazarus & Folkman, 1984; see Chapter 2), the allostatic load model (McEwen & Stellar, 1993; see Chapter 3), ACT (Eysenck et al., 2007; Nieuwenhuys & Oudejans, 2012, 2017; see Chapter 4), and CLA (Davids et al., 2008; see Chapter 5). Psychological (Manuscript 1), physiological (Manuscript 2), and behavioral stress responses (Manuscript 3) in police service were assessed to demonstrate their effects on performance, training, and long-term health. In doing so, temporal dimensions of physiological stress mediators were acknowledged by examining both baseline functioning and temporal patterning (Manuscript 2). Considering response inhibition as a central skill for goal-directed behavior in police service, coping was defined as the investment of extra mental effort to prevent the shift from goal-directed to stimulus-driven attentional control (Manuscript 4). Finally, (virtual) police training under stress was shown to be a promising method to strengthen officers' coping resources, coping, and performance (Manuscript 4). Evidence on perceived stressors provided valuable insights to build representative scenarios in police training (Manuscript 5). To summarize the results of the dissertation, theoretical, methodological, and practical implications of the combined findings are discussed in the following.

6.1. Lack of Psychophysiological Correspondence in Police Service

In light of the various occupational stressors (see Section 2.2), policing is considered a highly stressful job. Nevertheless, in Manuscript 1 and 2, the officers reported relatively low to medium stress levels, suggesting that the impact of specific occupational stressors has generally been overestimated. Moving beyond the mere assessment of stressors, results in

Manuscript 1 have shown that it is crucial to examine the complete stress appraisal process including intra- and interindividual differences in coping resources. For instance, preparedness through training has emerged as an important coping resource that decreased perceived stress levels during the COVID-19 pandemic. Notably, the influence of perceived coping resources might also transfer to behavioral stress responses and make the decisive difference between peak performance and performance failure in high-stress situations. The Biopsychosocial Model of Challenge and Threat (Blascovich, 2008) proposes that an individual in a challenge state – characterized by the existence of coping resources – outperforms an individual in a threat state – characterized by the absence of coping resources. As such, the appraisal of coping resources might indeed have practical significance for police performance and training: While police training might (subconsciously) strengthen coping resources through the acquisition of police-specific skills (see Manuscript 1) and situation-specific coping strategies to counteract stress-related impairments in attention (see Manuscript 4), it might also be beneficial to make officers consciously aware of their coping resources.

However, by employing a multi-method approach, the current dissertation revealed discrepancies between the self-reported and physiologically measured stress levels among officers. Despite the rather low to medium self-reported stress levels in Manuscript 1 and 2, data on physiological stress markers in Manuscript 2 suggests severe physiological stress load among officers (i.e., allostatic load). Additionally, we showed in Manuscript 2 that physiological stress responses did not increase in moments of perceived stress (in line with Giessing et al., 2019; Strahler & Ziegert, 2015). For decades, coherence between the cognitive-emotional and physiological stress responses - composing a “single, synchronized system” (Abelson & Curtis, 1989, p. 565) - has been assumed (for a review see Mauss et al., 2005). However, in an influential review, Campbell and Ehlert (2012) found significant associations between cortisol responses and self-reported stress variables in only approximately 25% of the studies under investigation. They argued that psychophysiological interrelations between stress variables should not be studied without the consideration of moderating factors, such as methodological and interindividual differences. Following their argumentation, I argue that (1) physiological dispositions (e.g., HPA and autonomous nervous system baseline characteristics; Manuscript 2) and (2) psychological traits and states (e.g.,

social desirability, appraisal processes, and emotion regulation; Manuscript 1) might cause the observed discrepancy and moderate the stress processes in police service[11].

On the physiological level, the results in Manuscript 2 clearly demonstrated that the assessment of chronic stress responses is crucial to fully understand the stress reactivity in acute stress-situations during police service. A critical incident during police service does not occur in isolation, but its timing must be considered in relation to the officer's life cycle (Lazarus & Folkman, 1984). Police officers are very likely to have a history of continued or frequent exposure to stressors or limited energetic resources available (see Section 4.3), all of which can lead to a state of allostatic load with chronic dysregulations of the physiological stress systems (McEwen & Stellar, 1993). The altered HPA and SAM baseline characteristics among officers (see Manuscript 2; in line with Allison et al., 2019; Charles et al., 2016; Fekedulegn et al., 2012, 2018; Planche et al., 2019; Violanti, Fekedulegn et al., 2017; Wirth et al., 2011) might explain the observed hyporesponsivity resulting in the distinct psychological and physiological stress responses to acute stress. In light of the negative consequences for long-term health (Adam et al., 2017; McEwen & Stellar, 1993) and potentially for performance in acute situations (see Section 4.4.), research attention should be directed to (possibilities of) physiological recovery processes in police service. It has been suggested that poor recovery from stress may contribute more to long-term health problems than the magnitude of the stress response itself (Brosschot et al., 2005). Given the frequent exposure to stressors in police service, it would be adaptive for officers when stress responses quickly return to initial resting levels after the stress situation in order to be ready to face a new stressor (e.g., Laborde et al., 2018; McEwen & Stellar, 1993). So far, there is only a limited number of studies examining the ability to recover from stressors among police officers. Our finding of no significant differences between daily averages on sCort, sAA, stress, or mood on off- vs. on-duty days might hint at officers' failure to recover from occupational stressors (see Manuscript 2; in line with Allison et al., 2019; Anderson et al., 2002), resulting in prolonged activation (see McEwen &Stellar, 1993). Consequently, future research should examine how recovery processes can be improved in police service. One possible way could be through enhancing performance in high-stress situations. In a recent study, participants

[11] Of note, I cannot rule out potential confounding influences of methodological features (e.g., assessment time, frequency, or tool). For instance, in the ecological momentary assessment in Manuscript 2, we assessed self-reported stress and saliva samples at a concurrent measurement point (see Schlotz, 2019). Event-based sampling in Manuscript 2 was delayed by 10 to 45 min, which is considered appropriate to capture sCort peaks, but might explain the missing sAA response as a marker for the fast-responsive autonomic stress response.

who had superior performance in prone rifle shooting showed a faster physiological recovery than those who performed poorly (Mosley et al., 2018), suggesting that maintaining performance in high-stress situations might facilitate recovery from stress situations.

On the psychological level, positive psychological states are assumed to show stronger associations with physiological responses due to their social acceptability, while negative psychological states are usually controlled (Mauss et al., 2005). This might be particularly true for police officers who are widely reported to have difficulties acknowledging or admitting negative stress experiences (Di Nota & Huhta, 2019). Clinical police psychologists describe police culture as an environment in which the open expression and sharing of anxiety, fear, or a traumatic experience are unacceptable (Papazoglou, 2013; Rudofossi, 2007). Speculatively, the reluctance to share stress experiences might explain why the critical incidents reported in Manuscript 2 did not exceed a rating of 5 on a stress scale ranging from 1 to 7, although four of the six incidents involved major operational stressors (i.e., use of force and confrontation with injured or dead persons; see Violanti et al., 2016). Given the organizational and legal mandate to remain calm and emotionally neutral (Papazoglou, 2013), officers are routinely required to regulate their emotions. Typically, police officers use emotion-regulation strategies such as denial, suppression, and overall avoidance of negative emotions (Berking et al., 2010; McCraty & Lawrence, 2016). Although emotional suppression may initially lessen the experience of negative emotions, it eventually has paradoxical effects leading to increased psychological and physiological stress responses (Gross, 2002). For instance, in Manuscript 1, we found that maladaptive emotion-regulation strategies (i.e., rumination and expressive suppression) were associated with higher stress levels, whereas adaptive emotion-regulation strategies (i.e., reflection, reappraisal, distraction, and social sharing[12]) were associated with lower stress levels. Similarly, the officer in Manuscript 2 who reported to mainly have used adaptive emotion-regulation strategies (i.e., reflection and acceptance) experienced no deteriorations in negative mood and energy in acute stress-situations. As such, the relatively low self-reported stress levels might be attributed to successful efforts to regulate the unwanted stress experience. Importantly, however, it remains unclear if an active regulation of stress responses might be counter-productive for performance in high-stress situations (for a detailed discussion see Section

[12] For the calculation of the two subscales of adaptive and maladaptive emotion regulation in Manuscript 1, we followed the results of Brans et al. (2013): They found that reflection, reappraisal, distraction and social sharing were related to increases in positive affect, whereas rumination and expressive suppression were related to increases in negative affect.

4.4.) or whether both occupational performance and long-term mental health of police officers would be protected by a police culture that acknowledges and accepts stress experiences as an inherent part of police service (Giessing & Frenkel, in press; Papazoglou, 2013).

6.2. Individual Stress Reactivity and Stress-Dose Effects on Police Performance

The individually and occupationally mediated differences in psychophysiological stress reactivity make it difficult to fully understand the underlying mechanisms of performance under stress among officers. Generally, stress is assumed to impair performance by shifting attentional processes from goal-directed to stimulus-driven control, although theoretical considerations suggest that performance can be maintained by investing extra mental effort (Eysenck et al., 2007; Nieuwenhuys & Oudejans, 2012, 2017). The results of the present dissertation contradict these theoretical assumptions and suggest that the ability to inhibit prepotent responses can be maintained under emotional and physical stress (see Manuscript 3). On the contrary, it can be cautiously derived that response inhibition might be a promising compensatory mechanism in which officers should invest extra mental effort to maintain performance under stress (see Section 4.4). However, the literature on the effects of emotional and physical stress on response inhibition is sparse and therefore, does not allow robust conclusions for practical implications yet. As a first step, further insights on the effect of stress on performance could be offered by considering the individual stress reactivity (Krypotos et al., 2011; Roos, Knight, Beauchamp, Berkman et al., 2017; Shields et al., 2015). Following the argumentation of various moderators on stress reactivity in Section 6.1, future research on performance under stress should at least assess and statistically control for individual stress reactivity by measuring stress biomarkers in addition to self-reports, especially in police samples. Importantly, there is preliminary evidence that police officers may show attenuated stress responses to acute stressors (see Manuscript 2; in line with Giessing et al., 2019; Strahler & Ziegert, 2015). Therefore, generalization of results in healthy samples without any police background (as in Manuscript 3) need to be treated with caution.

Although considerable research has supported the proposed attentional disruptions under stress in police service and other contexts (see Section 4.1 und 4.2), clearly, ACT is not without limitations (see Eysenck & Wilson, 2016). It focuses on the effects of maladaptive stress responses, while it neglects the idea that acute stress responses might actually be adaptive in the sense of allostasis (McEwen & Stellar, 1993; see Section 3.2). Based on Yerkes and Dodson's (1908) seminal work, stress is assumed to influence performance on an inverted U-shaped continuum: Specifically, when an individual experiences no or little stress,

increasing the stress level also increases performance until a threshold is exceeded; thereafter, performance declines with increasing stress levels (e.g., Hardy, 1990). Interestingly, this relationship extends beyond the psychological construct of stress to stress-response processes in other fields (e.g., evolutionary biology, medicine, toxicology) and is called *hormesis* (for reviews see Calabrese & Mattson, 2011; Costantini et al., 2010; Agathokleous et al., 2018). Hormesis describes the relationship between the dosage of a potential harmful stressor and the response it triggers in an organism: If the dosage is too small, it may yield no or only a small beneficial effect; if the dosage is too large, it may trigger harmful responses. In order to elicit a desirable response, an optimal dosage of stress must be defined. Consequently, theories on performance under stress could benefit from taking stress-dose effects into account instead of a binary comparison of stress vs. no stress. Besides inter-individual differences in the stress reactivity to the same stressor (see Section 6.1), individuals might also differ in their hormetic curve. That is that two individuals might respond, cope, and ultimately perform differently when facing the same stressor. Thus, it is necessary to individualize stress-performance relationships (e.g., Hill et al., 2020).

One barrier to the application of the hormesis approach to performance under stress has been the lack of objective real-time assessments to accurately map changes in stress levels and performance in dynamic settings (Hill et al., 2020). Performance in critical police incidents should be studied as dynamic process rather than focusing on the outcome of the situation (Bennell, Alpert et al., 2021). Officers who actually differ in their ability to adapt to stress might not be differentiable on a particular, standardized scenario (e.g., one of average stress intensity). However, when the stress intensity of the scenario is increased, the performance of the officers might start to deviate (Kiefer et al., 2018). Thus, a complete assessment must build a performance profile of officers across a variety of environments (from low to high stress). In this regard, VR offers novel, promising research possibilities by allowing real-time tracking of stress levels and performance parameters in representative environments under high experimental control (see Manuscript 4; Giessing & Frenkel, in press; Kiefer et al., 2018). The current standard hardware can already capture behavioral data, such as intra- and interpersonal positions, accelerometry, and fields of view. Additionally, efforts are undertaken to include physiological measurements to monitor stress into VR systems, such as breath rate, brainwave activity, and heart rate variability (Brammer et al., 2021; Muñoz et al., 2020). Exposing officers to various (virtual) police scenarios (ranging from low to high stress) while measuring real-time data will result in individualized stress-performance profiles. Theoretically, these profiles allow more fine-graded analyses of the

mechanisms underlying performance under stress in order to model action adaptation to stress (Hoffmann et al., 2018). Practically, they can provide highly valuable information for the design of police training under stress following a CLA (see Manuscript 4): The identification of stress levels that are expected to trigger optimal performance (see Hill et al., 2020) could guide police trainers in adopting the scenario and its constraints according to the individual hormetic curve of each trainee (see Section 5.1; Kiefer et al., 2018). Individualized training scenarios with more fine-grained adjustments of stress-inducing constraints broaden the range of conditions under which the trainee is able to cope with stressors (Kiefer et al., 2018). Importantly, training environments do not need to encompass representations of all potential stressors the officer may face on duty. The hormetic training approach promotes coping and behavioral adaptation (i.e., investment of extra mental effort; see Section 4.4) relative to changing constraints and thus, expands beyond the stressors experienced during training (Kiefer et al., 2018).

6.3. Bridging the Gap between Science and Practice: Future Research Directions

In critical incidents, police officers rely on skills acquired during training as an important coping resource (see Manuscript 1). Given the difficulty of skills execution under stress (see Section 4.2), the limited number of training hours poses a severe risk to the success of police training (Renden et al., 2015). Again, this highlights the importance to integrate evidence-based practices into police training that have empirically been shown to be effective and efficient (Arble & Arnetz, 2021). Fortunately, there is a rich literature on theoretical considerations (see Manuscript 4) and scientifically-validated techniques (e.g., Low et al., 2021; Körner et al., 2021) that can inform and guide training practices to prepare officers for performance under stress. Nevertheless, the implementation of these evidence-based practices still remains challenging and requires further research efforts evolving with new data and results (Arnetz & Arble, 2021).

Although training under stress can be considered as scientifically validated (Low et al., 2021; also see Commentary #2 by Arne Nieuwenhuys in Bennell, Alpert et al., 2021), valid data on representative constraints in order to induce stress in training scenarios is rare (see Section 5.2). Police recruits criticized that police training primarily focused on dealing with extreme stressors, which differed from the experiences they had made on duty. Continuously perceiving social situations as threatening and dangerous in training would transmit a grim world scheme, which might be a risk factor for aggressive police behavior (Staller, Körner, Heil, Abraham, & Poolton, 2021). Analogically, there is an overrepresentation of extreme

scenarios in the current scientific literature on police performance under stress (Giessing & Frenkel, in press), which makes it difficult to derive evidence-based recommendations for the use of representative stressors in training scenarios. In order to robustly elicit stress responses, simulated critical incidents in empirical studies usually require the use of gunfire (e.g., in hostage-taking, house searches, traffic stops, robberies, domestic violence, and knife attacks; for an overview see Giessing & Frenkel, in press). Yet, data on real-world policing reveals that very few police interventions involve the presence of weapons or even a gunfight (Baldwin et al., 2019). Nonetheless, police officers exhibit heightened stress responses during these operations and on duty in general (Manuscript 2; Anderson et al., 2002; Baldwin et al., 2019). Hence, training under stress should include training for presumably routine interventions without lethal force (Giessing & Frenkel, in press; Staller, Körner, Heil, Abraham, & Poolton, 2021), requiring valid data on representative stressors in such routine interventions from real-life critical incidents (see Section 5.2). Following from the promising hormetic approach (see Section 6.2), more research is needed about the stress-inducing potential of single stressors instead of complete scenarios to enable the individualization of scenarios to the hormetic curve of each trainee.

In the dissertation, I proposed VR as a promising tool to implement training under stress in police training (see Section 5.3). Despite the supposedly unlimited possibilities in scenario creation (see Manuscript 4), there seems to be a consensus that VR training should rather supplement the existing training practices than replace them (Haskins et al., 2020). I assume that traditional training is much better suited to train motor movement sequences such as shooting, self-defense, and arrest skills (due to the threat of the development of unnatural motion patterns in VR; Manuscript 4). Nevertheless, I hypothesize that training in immersive virtual environments outperforms traditional scenario-based training in serving the training objectives of searching hazards (perception), assessing the situation (interpretation), and taking appropriate actions (action; see Nieuwenhuys & Oudejans, 2012, 2107). Consequently, intervention studies aiming at examining the effectiveness should not only compare VR training vs. real-life scenario-based training, but also include a combined training condition in which trainees receive both VR and real-life training. Comparable to the result patterns known from mental imagery interventions (e.g., Driskell et al., 1994), I expect that the combined training will result in better performance than real-life training alone than VR training alone.

Another key challenge for future research will be the identification of strategies for teaching police-specific skills and the effective investment of extra mental effort (see

Manuscript 3) in training under stress. A preliminary study on CLA in police training has revealed that the lack of declarative knowledge and trainer feedback on an ideal technique resulted in considerable uncertainties among the trainees (Körner et al., 2021). Since the perception of available coping resources might be critical for perceived stress and performance, it can be assumed that trainees might benefit from conscious knowledge of the acquired skills (see Section 6.1), However, explicit motor learning (i.e., through specific instructions how to position and move) may cause the trainee to reinvest this explicit rule-based knowledge under stress, which in turn might result in performance decrements as attention shifts towards explicit rule-based knowledge (reinvestment theory; Masters & Maxwell, 2008). In light of the seeming contradiction, future research needs to assess to which degree police training should provide trainees with explicit skill knowledge.

Importantly, future studies on police training under stress should not focus on performance improvements, but take potential long-term effects on stress processes and health into account. Frequent exposure to high-stress training scenarios might habituate trainees to specific stressors over time, thereby extinguishing potentially adaptive stress responses for optimal performance in real-life critical incidents (see Section 6.2). To ensure that training under stress improves behavioral coping with stressors without interfering with the baseline functioning of physiological stress systems, more research into the intensity and frequency of training sessions is needed (Engelbrecht et al., 2019). Additionally, police training should incorporate psychoeducation about adaptive coping strategies that promote recovery and protect against negative effects of accumulating chronic stress (see Manuscript 2). Previous research has shown that shift work and sleep deprivation contributed to the stress-related dysregulation of physiological systems (e.g., Charles et al., 2016; Fekedulegn et al., 2012, 2018; Gerber, Hartmann et al., 2010; Wirth et al., 2011) with potentially deleterious effects on performance under stress (van Peer et al., 2019). To counteract these effects, sleep hygiene and fitness trainings have been suggested as valuable additions in health promotion programs in police service (Gerber et al. 2014; Schilling, Colledge et al., 2020; Schilling, Herrmann et al., 2020).

6.4. Conclusion

This dissertation aimed at providing a comprehensive understanding of psychophysiological stress processes and their relation to performance and training in police service by employing multiple measurement methods. Clearly, stress reactivity in police service is a highly complex phenomenon involving several response systems, namely

cognitive, emotional, physiological, and behavioral responses. Promisingly, the results of the dissertation demonstrate that police officers report low to medium stress levels when taking their perceived coping resources into account (see Manuscript 1). More importantly, it has been shown that goal-directed performance under stress can be maintained (see Manuscript 3) and trained in representative training scenarios (see Manuscript 4). However, the specification under which circumstances and how performance can be maintained and trained under stress is still outstanding. Nonetheless, physiological profiles of police officers alarmingly constitute police service as a major stressor causing states of allostatic load with hyporesponsivity to acute stress among officers with unknown consequences for performance and long-term health (see Manuscript 2). Future research is needed to inform the representative learning designs and complementary learning techniques in (virtual) police training in order to increase officers' level of preparedness for high-stress incidents and their long-term health (see Manuscript 5). Naturally, it is impossible to remove all stressors from police service and stress remains a central topic in police. Acknowledging and accepting the presence of stress in police service thus offers the opportunity to actively engage in coping, adapt to stressors, and eventually grow from stress.

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Appendix A1 – Manuscript 1

Note:

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The impact of the COVID-19 pandemic on European police officers: Stress, demands, and coping resources

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ABSTRACT

Purpose: Facing the COVID-19 pandemic, police officers are confronted with various novel challenges, which might place additional strain on officers. This mixed-method study investigated officers' strain over a three-month-period after the lockdown.
Methods: In an online survey, 2567 police officers (77% male) from Austria, Germany, Switzerland, the Netherlands, and Spain participated at three measurement points per country in spring, 2020. Three-level growth curve models assessed changes in strain and its relation to stressor appraisal, emotion regulation, and preparedness through training. To add context to the findings, free response answers about officers' main tasks, stressors, and crisis measures were coded inductively.
Results: On average, officers seemed to tolerate the pandemic with slight decreases in strain over time. Despite substantial variance between countries, 66% of the variance occurred between individuals. Sex, work experience, stressor appraisal, emotion regulation, and preparedness significantly predicted strain. Risk of infection and deficient communication emerged as main stressors. Officers' reports allowed to derive implications for governmental, organizational, and individual coping strategies during pandemics.
Conclusion: Preparing for a pandemic requires three primary paths: 1) enacting unambiguous laws and increasing public compliance through media communication, 2) being logistically prepared, and 3) improving stress regulation skills in police training.

While most critical, highly threatening police incidents, such as terrorism, only impact a limited geographic area for a short time, the COVID-19 pandemic has spread globally and has continued to be a public health emergency for an extended period of time. During pandemics, law enforcement agencies (LEAs) play a crucial role in the effort to control the spreading of the disease, maintaining public order and promoting safer communities. In order to protect the health of residents, unprecedented strict governmental measures have been enacted. In their responsibility to enforce these measures, street patrol officers are confronted with various challenges: the constant risk of infection, changing governmental measures leading to a shift in calls for services, and numerous alterations in policing protocols (Stogner, Miller, & McLean, 2020). All of those may lead to uncertain or potentially stressful situations, in which officers are still expected to decide and act appropriately. As such, it is critical to quantify the scope of the impact of the COVID-19 pandemic on officers in order to justify and properly target resources that allow LEAs and officers to cope with the pandemic (Stogner et al., 2020). The present study investigated (1) the working demands police officers face, (2) the perceived individual, organizational, and governmental resources to meet these demands, and (3) how they interact to determine the strain of the pandemic on police officers. These insights are intended to inform, update, and improve police leaders' and policy

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makers' understanding of preventive training and effective crisis management in pandemics to ensure that LEAs can continue to provide community services while protecting police officers' health and well-being.

According to the Transactional Stress Theory (Lazarus & Folkman, 1984), stress results from the individual's perception of a discrepancy between the environmental demands placed on him/her and his/her coping resources present in a particular situation. In this cognitive appraisal process, the individual judges on the one hand the stressfulness of the environmental demands (the so-called *stressors*) and on the other hand the availability and effectiveness of coping resources to meet these demands. When the individual perceives the stressors as exceeding his/her coping resources, a negative, unpleasant psychological state of stress ensues, commonly accompanied by fatigue (Doerr et al., 2015; Strahler & Luft, 2019) and deterioration in mood (Giessing et al., 2019; Lieberman et al., 2016; Schlotz, 2019). In this sense, the central mechanism posited in the Transactional Stress Theory (Lazarus & Folkman, 1984) shows similarities to the mechanism proposed by the General Strain Theory (GST; Agnew, 1992), which explains why individuals might engage in deviant behaviour. In both accounts, adverse environmental demands (e.g., failure to achieve a goal, the removal of positive stimuli or the exposure to negative stimuli) lead to stress or strain in the absence of adequate coping strategies. Importantly, the appraisal of the stressors and coping resources is constantly updated and may change rapidly dependent on the circumstances (Lazarus & Folkman, 1984).

Besides the well-known stressors in police work (Giessing et al., 2019; Violanti et al., 2016; Violanti & Aron, 1995), the COVID-19 pandemic places a high number of novel environmental demands on police officers. Most obvious, the risk of infection with COVID-19 is an additional threat that jeopardizes officers' health and lives (Drake & Altheimer, 2020; Jennings & Perez, 2020; Milliard & Papazoglou, 2020; Stogner et al., 2020). Due to the nature of police work, officers need to be physically present in order to serve and protect communities. During their shift, they come into contact with a large number of colleagues and civilians, whose COVID-19 status is often unknown, requiring officers to be increasingly hypervigilant of their environment (Stogner et al., 2020). Moreover, critical tasks (e.g., arrests) require them to violate guidelines on social distancing, increasing the risk of infections. At the same time, police officers face new types of threatening and hazardous behaviour by assailants through intentional contamination, such as spitting attacks (Jennings & Perez, 2020). While personal protective equipment (PPE) could reduce the risk of infection, the sufficient availability of appropriate PPE – even for critical infrastructure - was uncertain at the outbreak of the pandemic (Sim, 2020; Stogner et al., 2020). Naturally, the number of infected or self-quarantined officers was predicted to increase over the course of the pandemic, which might result in staff shortage and higher workload for those left in the work force (Drake & Altheimer, 2020; Milliard & Papazoglou, 2020). As a result, and to prevent spreading within the police force, shift schedules and working hours have been adjusted (Jennings & Perez, 2020). In European countries, LEAs have transitioned their personnel to work remotely if possible, instituted a 50/50 work plan to keep two groups within each department completely separate from each other, and suspended in-service training (e.g., in Austria, Germany, and the Netherlands). Additionally, the public health measures put in place by the governments have created novel tasks and procedures that needed to be implemented by the police officers at short notice (Stogner et al., 2020). These governmental measures have also led to a shift in crime and service (e.g., "criminalizing" common behaviours such as gathering with friends; Campedelli, Aziani, & Favarin, 2003; Mohler et al., 2020). In this context, officers are more likely to experience high-stress encounters with anxious or intransigent individuals aggravated by the fear of contagion, economic uncertainty, and isolation, especially since the new policies have been challenged on political, economic, and legal grounds (Stogner et al., 2020). Therefore, the COVID-19 pandemic is hypothesized to be a significant stressor for officers compounding the general work stress associated with the occupation. While all of these demands are described as potentially stressful in the literature (Drake & Altheimer, 2020; Jennings & Perez, 2020; Milliard & Papazoglou, 2020; Stogner et al., 2020), targeted crisis management should primarily address those that are perceived as threatening by the officers, thus taking their lived experience into account.

Despite all the potential stressors, the availability of coping resources will determine whether they result in higher stress levels than usual or not. Emotion regulation is an essential individual coping resource to be considered in this context. Adaptive emotion regulation strategies (e.g., reappraisal) have been shown to decrease negative affect and increase positive affect, while maladaptive strategies (e.g., suppression) increase negative affect and decrease positive affect (Brans, Koval, Verduyn, & Lim, 2013; Katana, Röcke, Spain, & Allemand, 2019; Richardson, 2017). In the context of emotion regulation of work stress, work experience has been found to decrease perceived stress and increase related well-being (Katana et al., 2019) and stress reactivity to police incidents (Landman, Nieuwenhuys, & Oudejans, 2016). When considering individual differences, the COVID-19 pandemic might differentially affect stress levels of men and women as there are large gender differences in police stress in general (Violanti et al., 2016) and in response to the 9/11 terrorist attack (Bowler et al., 2010), with women being more stressed. Identification of governmental, organizational and individual characteristics and behaviours linked to successful coping is needed so that the actions can be replicated by other LEAs and officers. More importantly, an understanding of vulnerable officers and lacking coping resources can assist LEAs in directing resources towards their officers in most need (Stogner et al., 2020).

Officers are expected and trained to respond to danger and crises. Therefore, police training should have equipped them with necessary coping resources to resolve crisis situations effectively (Milliard & Papazoglou, 2020). Additionally, governments and police organizations have introduced legal decrees and procedures to meet the demands of the pandemic (European Centre for Disease Prevention and Control, 2020; International Association of Chiefs of Police (IACP), 2020; Jennings & Perez, 2020). While some of these measures may be helpful, they might also have detrimental effects on officers' productivity and well-being. Constantly altered safety protocols and policies might limit officers' attention and complicate interaction with civilians (e.g., PPE may impair field of vision, breathing, and grip on objects; Stogner et al., 2020).

Since the police carries great responsibility in the effort to control the spread of COVID-19, effective management of the demands of the pandemic is crucial to protect police officers' functioning, well-being, and health. Given that stress can have tremendous consequences on performance (Nieuwenhuys & Oudejans, 2017) and health (McEwen & Stellar, 1993), one approach to safely lead police officers through the pandemic is to reduce their strain by strengthening their coping resources. So far, stressors and avenues for providing officer support have only narratively been discussed in the literature, but no empirical data has been collected (Jennings & Perez, 2020; Milliard & Papazoglou, 2020; Stogner et al., 2020). The present study aimed at filling this research gap by exploring the relationship between police officers' work stressors, coping resources, and stress during the pandemic. Police officers' perceived stress, mood, and fatigue (collectively representing the strain they experience) were repeatedly measured throughout a 11-week period during the COVID-19 pandemic to reveal how officers were coping at each specific time point. At the outbreak of COVID-19, the development of the pandemic as *stressor* as well as the effectiveness of the governmental, organizational and individual measures as *coping resources* were unclear. Therefore, we hypothesized that officers' strain would vary over the course of the pandemic (hypothesis 1). While all European countries have been impacted by COVID-19, governmental measures and their timelines to contain the spread of the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) differed among countries (European Centre for Disease Prevention and Control, 2020).

Therefore, it was assumed that officers' strain varies between countries (hypothesis 2). Previous research has suggested interindividual differences in police officers' stress reactivity based on sex (Bowler et al., 2010; Violanti et al., 2016) and work experience (Landman, Nieuwenhuys, & Oudejans, 2016). Therefore, we assumed that women would report higher stress levels than men (hypothesis 3), while work experience would reduce stress responses (hypothesis 4). Building on the stress model (Lazarus & Folkman, 1984), time-variant differences in the appraisal of the stressors as well as the effectiveness of coping resources will also impact officers' strain. We assumed that negative stressor appraisal of the pandemic would increase officers' strain (hypothesis 5). Addressing the appraisal of coping resources, we hypothesized that feelings of preparedness through training would decrease strain during the pandemic (hypothesis 6). Additionally, emotion regulation as a potential coping resource has been shown to influence work stress in other contexts (Katana et al., 2019). Therefore, we assumed that maladaptive emotion regulation would increase officers' strain, whereas adaptive emotion regulation would decrease strain (hypothesis 7).

For a proper understanding of the underlying causes and mechanisms of the strain police officers experienced during the pandemic, it is essential to include context to the quantitative analyses. Insights into the lived experience of police officers throughout the unprecedented times of COVID-19 measures are indispensable to arrive at an understanding of, and recommendations for, police work in times of a pandemic. We therefore augmented our study by incorporating open-ended questions to gain a more in-depth understanding of the impact of the COVID-19 pandemic on police officers' lives. We were especially interested in exploring the following questions to derive evidence-based recommendations for effective crisis management in European LEAs:

(1) What are officers' main tasks during the pandemic? Which work demands do police officers perceive as stressful?
(2) Which individual, organizational and governmental coping resources do police officers perceive as effective? In which areas do they perceive a lack of coping resources?

1. Method

The observational study was conducted in six LEAs in five European countries (Austria, Germany, Switzerland, the Netherlands and Spain/region Euskadi) during the COVID-19 pandemic from March 27, 2020 to June 5, 2020. LEAs were recruited through a consortium and its networks of an EU Horizon 2020 project that includes multiple European LEAs and investigates the feasibility of virtual reality in police training (i.e., SHOTPROS, https://shotpros.eu). To examine a large, diverse sample of officers, the participating LEAs widely distributed the survey online through mailing lists using SoSci Survey (www.soscisurvey.de). In a longitudinal approach, each LEA participated at three measurement waves with a survey period of one week and two weeks between the survey periods. Due to internal approval procedures, LEAs started the online survey at different measurement points. A detailed timeline of all participating countries can be found in Table 1.

1.1. Participants

Overall, 2567 police officers (77% male) participated in at least one measurement point of the online survey. Participants were between 19 and 65 years old ($M = 39.69$, $SD = 11.64$) and reported a range of 0 to 46 years of working experience ($M = 17.22$, $SD = 12.69$). The Austrian sample included 1415 participating officers from four different regions (Vienna, Graz, Tirol and Carinthia). The German sample comprised of two LEAs (Police Berlin; Police Baden Wurttemberg, Mannheim) with 711 participating officers. In Switzerland ($n = 325$), one police department (Stadtpolizei Zurich) participated. In the Netherlands ($n = 76$) and in Spain ($n = 40$), the National Police and the Policía Autonómica of Euskid participated, respectively. Demographics of the sample in each country can be found in Table 2.

Table 1
Study timeline and date of lockdown in each country.

	Lockdown	t_1 27 March to 02 April 2020	t_2 17 April to 23 April 2020	t_3 08 May to 14 May 2020	t_4 29 May to 05 June 2020
Austria	16 March 2020	Day 11 to 17	Day 32 to 38	Day 53 to 59	
Germany	23 March 2020	Day 4 to 10	Day 25 to 31	Day 46 to 52	
Switzerland	14 March 2020		Day 34 to 40	Day 55 to 61	Day 75 to 81
Netherlands	12 March 2020		Day 36 to 42		
Spain	13 March 2020		Day 35 to 41	Day 56 to 62	Day 76 to 82

The Social and Societal Ethics Committee of the KU Leuven provided ethical approval for this study (approval number: G-2019 081712). Informed consent was obtained from the participating officers. Participants received no financial compensation.

1.2. Measures

To ensure high participation rates and to keep interference with official duties minimal, the survey was kept as short as possible. Therefore, questionnaires originally developed for ecological momentary assessment and a few self-drafted quantitative single items were used. Acknowledging the explorative nature of the study, several open, free response questions allowed participants to share the full range of their current experiences. All measures were translated into the respective language of each country. The completion of the questionnaire took on average 10–12 min.

1.2.1. Quantitative measures

Perceived stress was measured using the single item „During the last week, I felt stressed out", rated with a Likert scale ranging from 1 (*not at all*) to 7 (*very*).

Fati was measured using the single item „During the last week, I felt fatigued", rated with a Likert scale ranging from 1 (*not at all*) to 7 (*very*).

Participants' *mood* was measured by a six-item short version of the German Multidimensional Mood Questionnaire (Wilhelm & Schoebi, 2007). The items represent three bipolar scales of *valence, energy*, and *calmness* [unwell–well (V+), content–discontent (V–), tired–awake (E+), full of energy–without energy (E–), agitated–calm (C+), relaxed–tense (C–)]. Structural validity, sensitivity to change and reliability has been reported for this short scale (Wilhelm & Schoebi, 2007).

Stressor appraisal of COVID-19 was measured by four self-drafted items. Participants were asked to what extent they perceived the COVID-19 crisis as *stressful*, *challenging*, *controllable*, and *threatening* on a scale from 1 (*not at all*) to 7 (*very*). A total average score was calculated with one item being reverse coded (i.e., *controllable)*. The internal consistency was acceptable for all four measurement points ($\alpha > 0.71$).

The use of *emotion regulation strategies* was assessed by six items, each representing one emotion regulation strategy (Brans et al., 2013): „I have calmly reflected on my feelings" (*reflection*), „I have changed the way I think about what causes my feelings" (*reappraisal*), „I couldn't stop thinking about my feelings" (*rumination*), „I have talked about my feelings with others" (*social sharing*), „I have avoided expressing my emotions" (*expressive suppression*), and „I have engaged in activities to distract myself from my feelings" (*distraction*). Each item was rated on a seven-point scale ranging from 1 (*not at all*) to 7 (*very*). Following the results of Brans et al. (2013), two subscales of adaptive emotion regulation and maladaptive regulation were calculated by averaging the respective items: Adaptive emotion regulation comprised *reflection,*

Table 2
Sample description.

	Austria (n = 1415)	Germany (n = 711)	Switzerland (n = 325)	Netherlands (n = 76)	Spain (n = 40)	Total (n = 2567)
Age	38.05 (11.79)	42.20 (11.81)	39.80 (9.95)	44.13 (9.86)	44.38 (8.17)	39.69 (11.64)
Sex (m)	78%	72%	80%	74%	88%	77%
Working experience (in years)	15.34 (12.88)	21.63 (12.76)	14.63 (9.61)	20.40 (10.31)	18.44 (9.08)	17.22 (12.69)
Job Position						
Field Service	70%	37%	69%	46%	68%	60%
Patrolling Service	66%	34%	68%		65%	55%
Highway Patrol	1%	2%	2%		0%	1%
Border Control	3%	0%	0%		0%	2%
Police Cadet	1%	1%	0%		0%	1%
Office Service	22%	56%	26%	7%	4%	31%
Command Staff	15%	21%	11%		8%	15%
Criminal Investigator	5%	19%	3%		3%	8%
Case Processing	2%	15%	7%		3%	6%
Instructor	0%	2%	1%		3%	1%

Note. Job position was assessed by a free response question. Answers were categorized in the main categories Field Service and Office Service with respective categories.

reappraisal, distraction and *social sharing* as they were related to increases in positive affect, while maladaptive emotion regulation consisted of *rumination* and *expressive suppression* related to increases in negative affect (Brans et al., 2013).

Preparedness through police training was measured using the single item „How well did your police training prepare you for the current work demands during the COVID-19 crisis?" rated from 1 (*not at all*) to 7 (*very*).

1.2.2. Qualitative measures

The purpose of the open, free response questions was to explore officers' lived experiences and practices at various stages during the COVID-19 pandemic. In light of the main tasks during the pandemic, the survey sought to identify private and work-related stressors, effective measures taken before and during the pandemic, and availability of support. An overview of all open questions can be found in Supplement Table S1.

1.3. Statistical analysis

To verify a summary index of *strain*, a principal component analysis (PCA) was conducted on eight items of stress, fatigue, and the Multidimensional Mood Questionnaire. The aim was to obtain a parsimonious solution by explaining the variation in the original data set using only one underlying component. Reliability tests of Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy and communality values justified the use of PCA.

A multilevel growth curve approach was applied to analyze changes in strain over time during the pandemic. Multilevel modeling analyses were performed in R (R Core Team, 2020) using the lme4 package (Bates, Mächler, Bolker, & Walker, 2015) and lmerTest package (Kuznetsova, Brockhoff, & Christensen, 2017). A multilevel model assuming three levels was applied with strain (Level 1) nested within individuals (Level 2) nested within countries (Level 3). Random intercept models with fixed effects of Level 1 and Level 2 predictors on strain were specified. In Step 1, an unconditional means model with no predictor variables was built to understand the amount of variance in strain partitioned into within-person, between-person and between-countries variance. In Step 2, an unconditional growth model with time as a predictor variable was used to understand the extent to which within-person variation was a function of the passing of weeks since the lockdown (growth). Weeks since lockdown was a decimal number, which was calculated by dividing days since lockdown by 7. A quadratic trend was checked for by entering (weeks since lockdown)^2. In Step 3, fixed Level 1 effects of stressor appraisal, emotion regulation and preparedness (time-variant predictors) were added. In Step 4, the fixed Level 2 effects of work experience and sex (time-invariant predictors) were entered. For each Level 1 and Level 2 predictor, the interaction with the time predictor was checked and only remained in the model if significant. Prior to analyses, stressor appraisal and emotion regulation were centered around the within-person mean, thereby yielding within-subject predictors that vary within, but not between individuals (Curran & Bauer, 2011). Preparedness was centered around the within-country mean. Working experience was grand-mean centered. Models were estimated with Restricted Maximum Likelihood (REML). To compare model fit between nested models, we used Likelihood Ratio tests after refitting the respective models with Maximum Likelihood (ML). For unnested models, the Deviance (−2LL) statistic, Akaike information criterion (AIC), and Bayesian information criterion (BIC) were used to evaluate improvements in fit with each addition of variables to the model; decreasing values indicate improvements in fit. The significance level was set at $\alpha = .05$. Pseudo-R^2 at Level 1 was determined using the following equation: Pseudo-$R^2 = \frac{\sigma^2_{reference\ model} - \sigma^2_{final\ model}}{\sigma^2_{reference\ model}}$, where the reference model is the unconditional means model (Raudenbush & Bryk, 2002).

The open-ended questions were analyzed and coded based on the deductive category assignment in the qualitative content analysis according to Mayring (2014). For analyses, data units were derived from the answers of the respondents to the open-ended questions. Each data unit consists of an independently interpretable and meaningful unit. In some cases, the answer represented one data unit, whereas in other cases, the answers were split into multiple data units. This was done when an answer contained more than one meaningful unit and addressed more than one issue. As an example, when a respondent listed three work demands, this answer was split into three data units, each listing one work demand. The open, inductive coding was done with about 50% of the dataset, and with this selection of the data, no new codes came up. The developed coding structure was then deductively applied to the remainder of the data.

All data units were assigned to main categories, and most data units were assigned to subcategories within the main categories. If an answer could not be clearly assigned to any of the defined subcategories, it was sorted into a main category. An overview of all main categories and subcategories can be found in Supplement Table S1. Frequency of citations for each main category are reported for each measurement point and each country.

2. Results

2.1. Principal component analysis/summary index

A PCA was conducted on eight items (stress, fatigue, mood) without rotation. The KMO measure verified the sampling adequacy for the

analysis, KMO = 0.92 ("marvellous" according to Kaiser & Rice, 1974), and all KMO values for individual items were greater than 0.90, which is well above the acceptable limit of 0.50 (Kaiser & Rice, 1974). A one-factor solution with an eigenvalue above Kaiser's criterion of 1 (eigenvalue = 5.41) emerged and explained 68% of the variance. The items tired–awake (E+), agitated–calm (C+) and, unwell–well (V+) negatively loaded on strain (< 0.80). Factor loadings for stress, fatigue, content–discontent (V–), full of energy–without energy (E–), and relaxed–tense (C–) were above 0.78. Varimax rotation did not change the results.

The PCA verifies the use of a single summary index representing stress, fatigue and mood. *Strain* was calculated as the average score of all eight items, after items with negative loadings were reverse coded. In the subsequent analyses, strain was entered as the outcome variable in the multilevel growth curve models.

2.2. Multilevel growth curve models

In total, there were 3455 completed questionnaires. Participants completed an average of 1.35 (SD = 0.65) questionnaires. While 248 participants completed questionnaires at all three measurement waves, 392 participants filled out two and 1927 filled out one questionnaire. Descriptive statistics of strain and all predictor variables are presented in Supplement Table S2.

Table 3 summarizes the multilevel modeling results for strain. As evidenced by the decrease in Deviance, AIC, and BIC, each model improved in fit with each subsequent step. In the Unconditional Means Model, we partitioned the between-country, between- and within-person variation in strain (see Table 3). The intraclass correlation was 0.70 – in other words, 30% of the variation in strain occurred within each individual, 62% between individuals and 8% between countries. Model comparison showed that the three-level-model had a better fit than the two-level-model ($X^2(1) = 110.96$, $p < .001$), indicating that levels of strain do vary between countries.

We examined the growth of strain as a linear and quadratic function of weeks since lockdown. Results indicated that across all participants, weeks since lockdown significantly predicted strain (see Table 3). A quadratic term of time did not significantly predict strain (Estimate = −0.001, $SE = 0.002$, $p = .63$) and did not improve the model fit, $X^2(1) = 0.23$, $p = .64$. Thus, there was a slight, but significant linear decrease of strain over time.

Next, we tested whether stressor appraisal, adaptive and maladaptive emotion regulation and preparedness predicted strain in police officers. Stressor appraisal and maladaptive emotion regulation were positively associated with strain, whereas preparedness negatively predicted strain (see Table 3). Adaptive emotion regulation did not significantly predict strain. As indicated by the decrease in Deviance, AIC, and BIC, the model improved in fit compared to the Unconditional Growth Model.

In the final model, we added the Level 2 predictors sex and work experience. Sex was significantly associated with strain, with women being more strained (see Table 3). Work experience was negatively associated with strain (see Table 3). As indicated by the decrease in Deviance, AIC, and BIC, the entering of the Level 2 predictors further improved the fit of the model.

2.3. Qualitative results

Frequency of citations for each main category are reported for each measurement point in Table 4 and for each country in the Supplement Table S3. For each question, we will discuss two to three main themes that stood out from the data by high frequencies, changes, or differences between countries. In the following sections, these themes and their content are illustrated with citations from the present survey. Supplementary quotations can be found in the Supplement Table S4.

Table 3
Results of the hierarchical linear model predicting strain using restricted maximum likelihood.

	Unconditional means model	Unconditional growth model	Level 1 predictors	Level 2 predictors
Fixed Effects – Estimates				
Intercept	3.51 (0.18)***	3.73 (0.17)***	3.63 (0.17)***	3.56 (0.16)***
Weeks Since Lockdown		−0.04 (0.01)***	−0.02 (0.01)**	−0.02 (0.01)**
Stressor Appraisal			0.45 (0.06)***	0.46 (0.06)***
Emotion Regulation adaptive			−0.07 (0.04)	−0.09 (0.04)*
Emotion Regulation maladaptive			0.15 (0.03)***	0.16 (0.03)***
Preparedness			−0.10 (0.01)***	−0.10 (0.01)***
Sex (female)				0.22 (0.06)***
Working Experience				0.01 (0.00)**
Random Effects				
Variance Residual	0.57	0.56	0.51	0.50
Variance Individual (Intercept)	1.18	1.19	1.19	1.18
Variance Country (Intercept)	0.15	0.12	0.13	0.11
ICC, Level 3	0.08	0.06	0.07	0.06
ICC, Level 2	0.62	0.64	0.65	0.66
ICC, Level 2 nested within Level 3	0.70	0.69	0.72	0.72
Fit Statistics				
Number of Observations	3455	3455	3421	3077
Number of Individuals	2567	2567	2542	2261
Number of Countries	5	5	5	5
Deviance	11,184.4	11,157.3	10,899.5	9730.2
AIC	11,192.4	11,167.3	10,917.5	9752.2
BIC	11,216.9	11,198.1	10,972.7	9818.5
-2LL	−5592.2	−5578.7	−5449.7	−4865.1
Pseudo R^2		0.02	0.11	0.12

Note. ICC = Intraclass Correlation. Standard errors in parentheses. For all variables, higher values imply a higher level of the respective construct (a positive association implies an increase in strain with increasing parameters). Stressor appraisal and emotion regulation were person-mean centered, preparedness was group-mean centered within the respective country, and working experience was grand-mean centered.

*** $p < .001$.
** $p < .01$.
* $p < .05$.

2.3.1. Private stressors

Most of the officers (roughly 80%) did not report any private stressors, indicating that they either did not face any private stressors or that they did not want to report them in a survey conducted in an occupational setting. Among those that have reported private stressors, the two main themes of "worries about relatives" and "caregiving duties" emerged and were mentioned throughout the complete survey period (see Table 4).

Related to worries about relatives, officers mostly mentioned relatives' or friends' diseases or medical histories that might constitute them as risk patients. Some officers reported to have been faced with the death of a relative or friend.

Caregiving duties mainly consisted of childcare including home schooling. Some officers also mentioned this as a work stressor

Table 4
Frequencies of perceived private stressors, main tasks, work stressors, effective crisis measures, effective crisis prevention and wishes for support during the pandemic (in % of all coded answers).

	t_1	t_2	t_3	t_4
Private Stressors				
Caregiving Duties	**6.1**	**4.5**	**5.3**	0.0
Economic and Domestic Obligations	2.4	3.0	1.6	0.0
Health Concerns	3.6	3.1	3.4	**5.7**
Romantic Relationships	0.0	0.0	0.0	0.0
Social Distancing	0.0	0.0	0.0	0.0
Worries about Relatives	**6.6**	**7.4**	**6.6**	**8.6**
Empty/ No Answer	**81.3**	**82**	**83.1**	**85.7**
Main Tasks				
Border Control	2.0	1.5	1.6	0.0
Corona Patrol	**42.8**	**39.1**	**30.3**	**20.5**
Criminal Investigation	6.3	5.2	7.7	0.6
Emergency Call Taking and Dispatching	0.3	0.7	0.7	0.6
Management Tasks	**15.5**	**14.7**	**17.7**	**13.5**
Off Duty	0.4	0.7	0.8	0.6
Office Service Tasks	8.4	8.2	8.5	10.8
Usual Patrolling Service	**21.6**	**27.1**	**29.5**	**50.6**
Empty/ No Answer	2.7	2.8	3.2	2.8
Work Stressors				
Leadership Communication	**13.7**	10.1	8.2	1.8
None	**22.9**	26.0	**31.3**	**35.4**
Operational Tasks	2.1	6.2	4.9	**12.4**
Risk of Infection	**23.2**	**15.9**	**12.1**	**13.3**
Sense of Purpose	1.6	1.2	1.8	1.8
Uncertainty about Future	2.0	1.6	1.1	0.9
Uncertainty in Action	5.8	6.7	5.3	8.8
Working Circumstances	9.2	**11.7**	**13.7**	9.7
Working Hours and Annual Leave	9.1	10.0	7.9	3.5
Empty/ No Answer	10.4	**10.6**	**13.7**	**12.4**
Effective Crisis Measures				
Additional Authority for Action	2.0	2.1	1.7	2.4
Hygiene Measures	8.8	8.8	10.1	13.8
Information Supply	3.1	3.7	3.6	10.6
Measures of Restricted Civil Contact	**21.7**	**16.9**	**16.3**	13.0
None	**29.5**	**32.6**	**34.1**	**18.7**
Others	0.2	1.8	2.5	4.9
Personnel Measures	**16.7**	**18.1**	12.9	**17.9**
Social Support	0.8	0.3	0.1	0.0
Structural Adjustments	2.8	2.4	1.8	0.0
Unsatisfactory	0.8	1.4	1.6	4.1
Empty/ No Answer	13.6	11.9	**15.3**	**14.6**
Effective Crisis Prevention				
None	**47.9**	**46.9**	**45.4**	**31.3**
Off Duty Training	2.3	1.4	1.3	0.0
Organizational Resources	**11.6**	**12.5**	12	13.1
Police Training	11.1	10.9	**12.1**	**16.1**
Psychology	3.4	4.3	3.3	10.1
Work Experience	4.2	4.8	4.5	2.1
Empty/No Answer	**19.5**	**19.2**	**21.4**	**27.3**
Wishes for Support				
Compatibility of Work and Family	1.2	1.4	1.6	0.0
Corona Protection	**30.9**	**18.1**	**15.1**	**19.5**
Governmental Measures	5.4	7.3	6.1	5.3
Information Provision	**18.1**	**19.0**	**19.5**	**15.9**
Leadership Support	4.8	7.5	8.6	14.2
Personnel Adjustments	**11.6**	15.1	11	3.5
None	9.9	12.5	13.7	15.9
Empty/ No Answer	**18.1**	**19.1**	**24.4**	**25.7**

Note. Numbers in bold represent the three most frequently mentioned stressors.

indicating that caregiving duties interfered with their working hours. It is striking that this stressor is mostly apparent in the German and Austrian sample and less so in the other countries (see Supplement Table S3). Therefore, the decrease of caregiving duties should not be interpreted as a time effect, but rather reflects differences among countries.

2.3.2. Main tasks

Officers' tasks during the COVID-19 pandemic mainly included regular police tasks and the so-called "corona patrol".

Regular police tasks are considered as "*normal everyday business*" (male German officer, 53 years, t_3) including corona-unrelated patrols, vehicle controls, property protection and call for services in cases such as theft, domestic violence, disturbances or physical assault. Occasionally, officers observed an increase in cases of domestic violence.

Tasks of the corona patrol mainly aimed at being visible in the community, such as monitoring compliance with social distancing regulations, and patrolling critical infrastructure. Only a few targeted COVID-19 interventions such as vehicle controls or dissolving "COVID parties" were mentioned. In Austria and Spain, police officers were also responsible for the delivery of notifications about home quarantine and controlling the compliance. In this context, officers reported an increasing demand to care for the "*unsettled civil population*" (male Austrian officer, 59 years, t_1) by informing and educating about the current governmental measures and recommendations, either via phone in the office service or in conversations during patrols:

> *Police Department received/receives continuous and all-day phone calls asking questions about the current crisis. To be honest I/we felt like employees of a customer support hotline.*
>
> (male Austrian officer, 25 years, t_1)

At the beginning of the COVID-19 pandemic, police officers' main tasks focused on corona patrol. Regular police tasks seemed to be dispelled by these tasks initially, but then steadily gained in importance replacing the corona patrol (see Table 4). This apparent interference of the corona patrol with the regular police work was explicitly expressed by the officers, either through complaints about the extra workload or through the demand to neglect their regular tasks:

> *Mainly the monitoring of the social distancing rules. Most of the important police activities that were considered indispensable in the past are suddenly no longer relevant.*
>
> (male German officer, 44 years, t_1)

Given that the sample consists of ca. 15% command staff, their focus of police work during the COVID-19 pandemic was on management tasks including human resources planning, administration, and information supply. The command officers recognized the need for strong leadership by stating "*much leadership required*" (male German officer, 59 years, t_1).

> *Trying to cope with the flood of e-mails as well as innovations, instructions, service regulations, recommendations; trying to keep an overview; informing employees about current processes and legal situations.*
>
> (male German officer, 44 years, t_1)

2.3.3. Work stressors

While some officer reported severe signs of strain ("*I feel burned out*"; male German officer, 53 years, t_1), roughly a quarter of the officers stated to experience no work stressors with increasing numbers at each measurement point (see Table 4). At the beginning of the pandemic (t_1), the risk of infection and deficient leadership and communication emerged as the main stressors with decreasing numbers at each measurement point (see Table 4). Instead, working circumstances as stressor gained importance in the middle of the survey period.

The risk of infection included two facets: the risk of getting infected and being a risk for others, especially for family members. Two main reasons for the risk of infection as a stressor can be identified in the officers' reports: civilians' unwillingness to comply with the social distancing rules and the lack of PPE. At the beginning of the pandemic, many officers had no protection equipment at all, and supply of PPE was perceived as slow or inadequate (had to be bought by themselves or at team level).

Absolutely unsatisfactory protective equipment / the feeling that "the service and functioning of the police force prevails over police officer's health".

(male German officer, 55 years, t_2)

Uncertainty about whether you yourself have been infected or whether a colleague has been infected is psychologically very stressful, as there is a high probability that you will infect your own family.

(male Austrian officer, 25 years, t_2)

In the context of civilians' unwillingness to comply with social distancing rules, officers occasionally reported observations of increased potential of aggression against police authority:

The atmosphere outside is grimmer, […] *there is more resistance and rebellion towards cops.*

(male Dutch officer, 24 years, t_2)

Mentally unstable persons are overwhelmed by the crisis, which is why there is an increased number of police interventions, failure to keep a safe distance, persons who are overwhelmed with their feelings/fear and express this in aggression, unwilling to accept the danger of the virus or do not want to admit it.

(male Austrian officer, 43 years, t_2)

People are becoming more detached, more aggressive. That's what they vent on us police officers.

(female German officer, 49 years, t_3)

The perceived deficient leadership and communication at the beginning of the pandemic is mainly attributed to an information overload with daily changing laws, regulations, and orders that do not contain clear instructions for action. Some of these ambiguities seemed to appear on a governmental level due to legal vagueness ("*Legal imbroglio*"; male Austrian officer, 24 years, t_2) and rapid change of regulations. On the organizational level, the interpretation of the regulation and implementation of the measures had to be conducted at short notice. Some officers perceived this as a "*constantly changing actionism of the entire leadership*" (male German officer, 29 years, t_1). Additionally, some officers observed that responsibilities were not clearly assigned, leading to the "*occasional practice: many cooks spoil the broth.*" (male German officer, 60 years, t_1) and inconsistency in orders. In turn, the executive officers felt burdened by unfiltered, constantly changing information and unclear, inconsistent instructions both on the governmental and organizational level. This ambiguity in information resulted in an uncertainty of action, which did not allow "*a self-confident and correct intervention*" (Austrian officer, 28 years, t_1).

Changes and adaptations of the service to new needs. Interpretation of the rules. Implementation of the measures. Managing uncertainty.

(male Spanish officer, 57 years, t_3)

The rapid changes. What was valid yesterday is no longer valid tomorrow.

(male German officer, 50 years, t_1)

"What I need I won't get, what I get I don't need."

(male Austrian officer, 54 years, t_2)

In the context of the vague legal situation, for some officers, the enforcement of the governmental measures triggered dissonance between their actions and beliefs. Some officers did not perceive the corona patrols to be effective, especially because they came at the cost of cutting the regular criminal investigation. Other officers wondered about the righteousness of the governmental measures in the face of liberal, democratic principles. In this sense, some officers felt stressed by their accountability towards the civil population to only enforce legitimized, righteous regulations.

To curtail citizens in their fundamental rights is an unpleasant task.

(male Austrian officer, 42 years, t_3)

Due to an unclear legal situation and mediation by the government that certain activities are forbidden, although they are only recommendations without punishment, an expectation by the public arises, which I, due to the lack of a legal situation, cannot fulfil.

(male Austrian officer, 57 years, t_1)

For working circumstances in the middle of the observation phase, two main themes emerged. First, officers were bothered by the need to comply to all hygiene measures, especially wearing the oronasal masks in the patrol cars. Second, officers reported to be stressed by the need to socially distance themselves from their colleagues and by deteriorated team climate due to an overall intense situation.

2.3.4. Effective crisis measures

Roughly a third of the officers reported no effective crisis measures have been taken (see Table 4). Different reasons for this answer can be derived from their reports: a) no measures have been taken because no measures were necessary, b) measures should have been taken, but they were not, c) measures have been taken but were not sufficient or effective, and d) measures that have been taken aggravated the work.

There are no crises, these are home made!!

(male Austrian officer, 57 years, t_2)

None, since everything seems rather aimless and senseless.

(male German officer, 35 years, t_2)

None, there are too many and confusing. A clear, generally valid instruction for action and not constant changes would be necessary.

(male German officer, 35 years, t_1)

Measures taken are necessary but make everyday business more difficult.

(male German officer, 32 years, t_1)

The remaining officers mainly perceived three measures as effective: measures to restrict civil contact, personnel measures and the provision of PPE as a hygiene measure (see Table 4). It appears that the perceived effectiveness of these measures varies across the countries: In Austria, measures to restrict civil contact are mostly mentioned, whereas German and Dutch officers mentioned personnel measures more often. In Spain, hygiene measures seemed to be most important for the officers (see Supplement Table S3).

The measures to restrict civil contact can be differentiated into governmental and organizational measures. Both aim at reducing the number of contacts and therefore, the risk of infection. Governmental measures include the social distancing regulations, prohibition of access or residence in public spaces, event cancellations, and closure of restaurants, bars and night clubs. Police officers reported that those measures reduced passenger and car traffic resulting in smaller numbers of criminal offences. In this context, some officers explicitly commended the communication of the governmental measures as this has raised awareness in the civil population helping to justify police interventions.

No party scene, no alcohol, no prostitution, practically no bodily harm and assault during the night hours, our normal street life (party scene) has totally stopped. Only monitoring of the Covid19 measures.

(male Swiss officer, 61 years, t_2)

Raising public awareness through the political structures.

(male Swiss officer, 24 years, t_2)

Media communication of the measures as a basis for argumentation when intervening.

(male Austrian officer, 25 years, t_3)

Most of the organizational measures aimed at reducing public access and traffic within the police stations. Police officers mentioned measures, such as promoting online police services, changing the processes for police reports and limiting the conduction of police interviews to serious offences only. Clearly, those measures only targeted the officers in the office service, whereas officers in the field service seemed to benefit from the governmental measures. One officer explicitly stated that "*compliance with the COVID-19 measures led to a reduction in work only for the office service but this was far overtaken by the monitoring of measures*" (male Austrian officer, 50 years, t_3).

Regarding personnel measures, LEAs aimed at increasing the availability of personnel, while at the same time they implemented measures to limit the interaction between officers. The increased number of available officers was mainly achieved by the suspension of annual leave and in Austria by calling in police cadets. Both commanders and officers approved the suspension of leave. Commanders reported that the increased availability of personnel facilitated duty rostering, while executive officers noted the burden sharing between all officers resulting in reduced overtime hours and better planning reliability for leisure activities.

Noticeable caring measures by the employer (change in the shift roster/ regulations).

(male Austrian officer, 34 years, t_2)

Suspension of leave, as all available officials are on duty and the burden is therefore shared.

(male Austrian officer, 28 years, t_3)

However, having too much personnel on duty was also perceived as a risk of infection waves, especially when not limiting the interaction between officers. Consequently, LEAs were forced to implement measures preventing superspreading of the SARS-CoV-2 across the police force. Therefore, some officers were allowed to work from home if possible. However, some answers indicated that the unequal availability of home office possibilities might also cause conflicts within the police:

[…] *I expected more active support from the homeworkers! Not once did they come forward to assist. There are only a few colleagues of whom I know they were actually working.*

(female Dutch officer, 51 years, t_2)

Officers on duty in the departments perceived adjustments to the shift roster as effective, with different types of shift rosters being mentioned (e.g., rotating shifts, group service, 12- or 24-h duties). Additionally, some officers also mentioned fixed patrol dyads and the stop of replacements in other police stations. At the beginning of the pandemic, police officers reported that their departments operated at minimum number of staff which allowed them releases from service. The additional leisure time through releases from service was perceived as an opportunity for recreation and relaxation:

We have switched to A and B groups that do not meet.

(male German officer, 43 years, t_1)

The possibility of temporal and spatial separation through generous release from service regulations to maintain the functioning of my department.

(male German officer, 59 years, t_1)

The possibilities of release from service give possibilities to "switch off" and "come down" at home.

(female German officer, 26 years, t_1)

For hygiene measures, officers most frequently mentioned the supply with PPE . Additionally, they listed spitting protection in interviewing rooms, enforcing safety distance in the office or switching to telephone/ online conferences.

2.3.5. Effective crisis prevention

Nearly half of the officers reported that no measures in preparation for crises were taken (see Table 4). Analogous to the acute crisis measures, different reasons for this answer can be derived from the officers' reports: a) preventive measures should have been taken, but they were not, b) no crisis prevention was possible because the situation was unexpected and dynamic and, c) the measures taken were not sufficient enough. Irrespective of the judgment how prepared they felt, some officers pointed out that there was no specific crisis management or pandemic-specific training. Additionally, some officers perceived no crisis prevention measures on an organizational level, but emphasized the use of individual strategies.

None. The police are as overwhelmed as the citizens themselves.

(female German officer, 38 years, t_1)

There can be no advance provision for a crisis of this magnitude and nature, as there has been no such situation since the last world war. Measures in the preparation for a crisis could also not be anticipated by the employer.

(male Austrian officer, 58 years, t_2)

In general, the training is helpful; however, I believe that in the current situation, the character and nature of each individual influences the coping with COVID-19.

(male Austrian officer, 47 years, t_1)

The remaining officers perceived mainly three factors as effective in the crisis prevention: police training, general work experience, and organizational resources (see Table 4).

For police training, the officers mostly mentioned the transfer of skills acquired in scenario-based situational response training. The officers reported that the situational response trainings generally prepared them for "*unusual and chaotic situations*" (male German officer, 38 years, t_1). Foremost, they described self-protection as the key principle in training that has conditioned them to keep a safety distance to the police vis-à-vis. Additional skills acquired in the situational response training were target-oriented communication and stress regulation. Besides situational response training, officers also reported hygienic training and the understanding for legal regulations as effective crisis prevention measures in police training.

Self-safety is very important during the training. This idea is firmly anchored.

(female German officer, 29 years, t_2)

Distance and hygiene always play a major role in daily service/handling of people. No change, because you are "conditioned" for it.

(female German officer, 45 years, t_2)

Besides training experience, some officers reported work or life experience as an effective resource during the pandemic. They did not describe specific skills acquired through work experience, but rather summarized this as "common sense". Occasionally, officers reported that experiences and lessons learnt with other viruses (e.g., avian influenza) or crises (e.g., wave of refugees 2015/16) prepared them for the COVID-19 pandemic.

Experience, common sense, crisis management training in other contexts.

(male Spanish officer, 57 years, t_4)

Due to my decades of field service experience, the so-called crisis prevention is based on routine, common sense and simply listening to people.

(male Austrian officer, 53 years, t_3)

Organizational resources describe the self-concept as police and refer to competencies that are attributed to the organization and all its members. These competencies included hierarchy, flexibility of action, and competence of decision making. However, officers mostly mentioned internal channels of information, including emails, intranet, or support by COVID-19 task forces.

It's up to police officer to respond adequately to special situations. To be practical and solution-oriented. By definition, we are good at that.

(male Dutch officer, 51 years, t_2)

The ability of the police to be resilient and to cope with adversity.

(male Spanish officer, 57 years, t_3)

The fact that every day in the police service can bring the unexpected and requires mental and physical flexibility clearly helped to deal with the COVID19 crisis, in which new instructions and guidelines for action were communicated daily.

(female Swiss officer, 28 years, t_2)

2.3.6. Wishes for further support

[…] *We do not need blah-blah, but recognition without empty words* […] *Security that we will not end up spooning the soup, physically, financially and emotionally.*

(female German officer, 40 years, t_2)

In the officers' wishes for further support, three areas for action can be identified (see Table 4). First, further protection measures against SARS-CoV2 were requested, especially at the beginning of the pandemic and in Spain (see Supplement Table S3). This progression corresponds well with the findings on risk of infection as the main stressor at the beginning of the pandemic and that Spanish officers perceived the PPE as the most effective crisis measure. In the first half of the survey period, officers also suggested personnel adjustments (see Table 4), especially in Austria, Germany and Netherlands (see Supplement Table S3). Throughout the entire survey period, officers required improved forms of information provision (see Table 4).

Requests for further protection measures mainly comprised of the need for more and better PPE. Some officers even reported that they did not have any PPE at the beginning of the pandemic. Others reported that they needed to share too little resources among too many officers within their department and used privately acquired PPE. A few officers suggested widely applied testing or medical checks for police officers to minimize the risk of infections within the police force and in order to protect officers' families. Acknowledging the dilemma of more officers on duty (due to the suspension of annual leave) and the need to limit interaction, officers requested stricter policies for physical segregation of colleagues in departments and asked for hygiene information.

More protective equipment – It is widely reported in the media that police officers must now wear masks, but these are not available in sufficient numbers.

(male Austrian officer, 26 years, t_1)

For personnel adjustments, there are inconsistent reports whether personnel strength should be increased or minimum number of staff in the department should be decreased to limit interactions between officers. Therefore, some officers demanded building personnel reserves in order to maintain functioning in case of infections, including the approval of the suspension of annual leave for this purpose. Other requests targeted the organization of the working time: Some officers asked for more home office possibilities, while they also noted that adequate technical equipment needs to be provided in this case. Other officers claimed flexible working hours and an increase in resting periods (in some cases this meant stopping the suspension of annual leave).

As is the case in many departments, our department currently shows that too much personnel has been cut in recent years. Retired / transferred colleagues are only replaced after months / years or not at all.

(male Austrian officer, 34 years, t_1)

As there are currently a lot of colleagues on duty at the police departments due to a ban on leave, cancellation of training etc., it would be urgently necessary to keep a part of the staff in reserve. The distance regulations cannot be observed at my and many other police inspections, as far too many people are on duty. If someone should ever test positive, the whole service will be out of action for a long time. However, with a reserve of staff the service could be maintained.

(male Austrian officer, 56 years, t_2)

Officers' suggestions for information provision mainly targeted the style of communication. Information should be clearly structured and transparent. Various sources of information should be pooled into a single source to facilitate access to all relevant, up-to-date information (e.g., FAQ, newsletters once a day). Additionally, some officers asked for training including hygienic training as well as a general preparation for exceptional situations.

Superior departments and various task forces should pre-filter and compress information in order to contain the flooding of the first responders with new guidelines and information. Before new instructions and information are forwarded, the essential contents should be worked out.

(male Austrian officer, 33 years, t_1)

Hygiene training would perhaps be something, behaviour in exceptional situations and by this I mean other scenarios that could occur. A good preparation would certainly be helpful.

(female Swiss officer, 34 years, t_2)

Roughly 10% of the officers reported no further wishes for support during the COVID-19 pandemic, especially at the end of the survey period. There are slight differences between countries: While all Spanish officers asked for further support, a third of the Dutch officers mentioned no wishes (see Suppplement Table S3). It is striking that most of these reports comprised statements about general satisfaction with the measures. However, some limited this satisfaction to the current time point

indicating that they were not satisfied at the beginning of the pandemic or that the support might not be sufficient in the future (e.g., when the pandemic worsens). Interestingly, in the officers' compliments, they addressed coping at the individual, organizational, and governmental level:

> *Basically, everyone tries very hard to the best of their possibilities.*
>
> (male Austrian officer, 39 years, t_1)

> *The superiors and the command do what they can, currently no suggestions for improvement.*
>
> (male Austrian officer, 36 years, t_1)

> *In principle, I am satisfied with the measures taken by the Federal Government.*
>
> (male Austrian officer, 29 years, t_2)

3. Discussion

Police officers have faced a multitude of challenges during the COVID-19 pandemic, and they need support through an effective crisis management to successfully cope with the demands. LEAs must develop a realistic understanding of the officers' stress experiences as well as the different coping resources officers use to manage the distressing state. Such awareness is beneficial, not only to guarantee police functioning during pandemics, but also to facilitate officers' stress coping abilities and well-being. In a longitudinal design, the present study examined experiences reported by officers from five European countries from a stress and coping perspective. On average, officers seemed to tolerate the stress experiences during the pandemic with slight decreases of strain over three months after the lockdown. Although there is substantive variance of strain among countries, large inter-individual differences in strain were observed. Confirming our hypotheses, stressor appraisal, emotion regulation, preparedness, sex and working experience significantly predicted strain during the pandemic. Risk of infection and deficient leadership and communication emerged consistently as main stressors. In line with the large inter-individual variance in the statistical analyses, officers' perception of the effectiveness of various coping resources on a governmental, organizational and individual level differed greatly.

3.1. Police officers' strain appraisal processes, and coping resources during the pandemic

Overall, officers seemed to tolerate the stress experiences by the pandemic. At the day of the lockdown, an "average" officer (male, 17.22 years of work experience) had a medium strain level of 3.56 on a scale ranging from 1 to 7. Hypothesis 1 predicted that strain would vary during the pandemic dependent on the severity of the pandemic and the effectiveness of the crisis measures. Indeed, strain levels significantly decreased by 0.24 over three months after the lockdown (-0.02×12 weeks $= -0.24$). Therefore, it can be speculated that strain might have been slightly higher than usual at the beginning of the lockdown, although our data allows no comparison to strain before or after the pandemic. Since neither stress appraisal nor emotion regulation and preparedness significantly interacted with time after the lockdown, it remains unclear if the pandemic as stressor or the effectiveness of the coping resources caused the decrease in officers' strain. Nevertheless, the additional strain at the beginning of the lockdown might be explained through the reported extra work of corona patrols, which interfered with regular police tasks. After three months, most of the officers reported that they could return to regular police tasks, which reduced their work load. Since changes are rather small and officers are considered chronically stressed in the literature (Allison et al., 2019; Giessing et al., 2020; Planche et al., 2019; Violanti et al., 2016), it seems plausible to assume that the "average" officer was only mildly affected by the pandemic.

Confirming hypothesis 2, there was substantive variance between countries, with German officers being most strained followed by Spanish, Austrian, Dutch, and Swiss officers. The severity of the COVID-19 pandemic, its impact on the national health system, and the effectiveness of the governmental measures in each country as well as differences among the LEAs (i.e., federal vs. national police, different regions within one country) might account for these differences. Additionally, variance among the countries might be (partially) attributed to systematic differences in officers' demographic characteristics (i.e., sex and work experience; see Table 2), as indicated by reduced Level 3 variance when entering these variables in the final model (see Table 3). Despite the substantive variance between countries, most of the overall variance of strain in the final model (66%; see Table 3) was at the individual level, suggesting that interindividual differences determined strain more than differences between countries.

Confirming hypothesis 3, sex significantly predicted strain, with women being more strained than men (i.e., additional 0.21 on a scale ranging from 1 to 7). This finding is in line with literature on gender differences in police officers' perceived stress in response to the 9/11 terrorist attack (Bowler et al., 2010). Given that the pre-employment screening and training are similar for police women and men, the findings of elevated strain in women need to be further investigated to better understand its cause and to identify and implement preventive measures. Post-hoc analyses of cross-level interactions yielded a significant interaction of sex and preparedness indicating that men experienced less strain than women when feeling averagely prepared.

In addition, hypothesis 4 predicted that work experience would decrease work stress (Katana et al., 2019; Landman, Nieuwenhuys, & Oudejans, 2016). Indeed, work experience significantly reduced officers' strain during the pandemic. Officers' reports about work or life experience as a relevant coping resource affirm the statistical findings. The effect of work experience might be attributed to the appraisal of a higher availability of coping resources. Since work experience and age are correlated, it cannot be distinguished if specific police skills or general life skills were responsible for this effect. In line with hypothesis 6, feeling prepared for the pandemic through training significantly reduced strain. This finding is underpinned by officers' descriptions about the specific police skills that helped them to cope with the pandemic. Specifically, they mentioned keeping safety distance, communication skills and stress regulation which they have acquired in situational response training. However, there are also reports in which officers did not mention specific skills, but rather labelled it as "common sense". Following the line of general life skills, Katana et al. (2019) suggested that individuals with advanced age have learned how to use more efficient emotion regulation strategies. Dependent on the strategies, emotion regulation can either decrease or increase (work) stress and related stress responses (Brans et al., 2013; Katana et al., 2019; Richardson, 2017). Confirming hypothesis 7, engaging in maladaptive emotion regulation, i.e., rumination and expressive suppression, was associated with higher strain. In contrast, the use of adaptive emotion regulation, i.e., reflection, reappraisal, social sharing and distraction, reduced officers' strain during the pandemic.

Besides the availability of coping resources, hypothesis 5 predicted that strain would also be impacted by the stressor appraisal (Lazarus & Folkman, 1984). Negative appraisals of the pandemic as stressful, threatening, uncontrollable, and challenging significantly increased officers' strain during the pandemic. The use of the Transactional Stress Theory (Lazarus & Folkman, 1984) or alternatively the GST (Agnew, 1992) allows to explain police responses to stressful circumstances, such as pandemics or in use of force incidents and in the long run, to predict behaviour and to intervene if necessary.

In sum, while the "average" officer is rather moderately stressed by

the pandemic, the quantitative and qualitative results demonstrate that there is a large individual variance and diversity in the stress responses. Analyses showed that women, officers with less working experience or those not feeling prepared, appraising the pandemic as stressful and utilizing maladaptive emotion regulation are at risk to experience severe stress. Given the persistence of the pandemic, chronically elevated stress levels might jeopardize officers' psychological and physical well-being (McEwen & Stellar, 1993). Therefore, the identification of risk factors for less effective coping with COVID-19 related stress helps LEAs to direct their resources towards the officers in most need of mental health services.

3.2. Implications for effective crisis management

For effective crisis management in the pandemic, the perceived stressors need to be addressed on a governmental, organizational and individual level. From the officers' reports, two major stressors or areas of concerns consistently emerged: Risk of infection and information provisioning through leadership and internal communication to reduce uncertainty in action. Both the statistical and qualitative results of the present study allow to derive recommendations on how to successfully cope with these stressors.

3.2.1. Governmental measures

On the governmental level, the local lockdowns and social distancing policies, whether compulsory or voluntarily, were reported as facilitating the police work. This finding contradicts concerns in an American narrative that social distancing could increase the number of service calls due to violations of the policies (Jennings & Perez, 2020). Although reports of certain offences including vandalism and domestic violence have increased during the COVID-19 pandemic, overall, calls for services have slightly decreased (Campedelli et al., 2003; Mohler et al., 2020). Nevertheless, monitoring the compliance with the governmental measures on the corona patrol and educating civilians about the current regulations were officers' main tasks at the beginning of the lockdown. Therefore, the officers emphasized that clear, understandable laws are important for legitimized and self-confident police interventions. While public health departments lead the actual response to the pandemic, LEAs are expected to be "the voice of authority, calm, and guidance" (Brito, Luna, & Sanberg, 2009, p. 1). Consequently, officers are tasked with communicating the voluntary and mandatory measures, the values of compliance with these measures for the common good, reassuring frightened civilians, and the consequences for violations (Jennings & Perez, 2020). Governments have supported the officers in the enforcement of these policies by effective media communication and public safety initiatives. Nevertheless, we found reports of increased potential for aggression against police officers at an early stage of the pandemic in our data. Given the developments of violent riots during the pandemic (Stogner et al., 2020), e.g., in Stuttgart, Germany or Belgrade, Serbia, officers seem to be a sensor for rising social discontent with the governmental measures. Therefore, governments should take officers' experiences of increasing resistance seriously, implement early-warning systems to detect rising conflicts, and support the police in the prevention of social disorder by inclusive leadership and legitimacy of authority (Reicher & Stott, 2020). This is especially critical because public health policies during pandemics might also limit possibilities of positive interactions of the police with the community in outreach initiatives or community activities (Jennings & Perez, 2020).

3.2.2. Organizational measures

Officers' reports about the availability and effectiveness of organizational measures were inconsistent. While some officers perceived no measures at all or insufficient measures, other officers did list effective measures. However, even among those, the assessments of the effectiveness differed, since benefits and costs of each measure were considered and differently weighted. The measures perceived as effective by the officers were mainly aimed at reducing the risk of infection, which was identified as one of the main stressors. Above all, LEAs should prepare for pandemics by stockpiling PPE, including masks, gloves, gowns, eyewear, and hand sanitizer, to ensure an immediate and sufficient supply at all times (Brito et al., 2009; Jennings & Perez, 2020). However, prolonged use of PPE and adherence to safety health policies might distract police officers from other obligations, causing additional physical and mental fatigue (Chen et al., 2020; Stogner et al., 2020; Tsamakis et al., 2020). Therefore, LEAs should include the costs in their performance expectations and constantly re-evaluate the necessity of those measures based on officers' experiences. Secondly, LEAs reduced the risk of infection by personnel adjustments. To minimize the contact between officers, LEAs suspended roll-call and instituted 50/50 work plans by dividing the department's employees in half and keeping the two groups completely separate (also see Jennings & Perez, 2020). At the beginning of the pandemic, they also reduced the staff on duty or present in the departments through releases and possibilities to work remotely. However, the officers' reports showed that these measures require far-sighted planning (e.g., providing technical equipment for remote work) and good internal communication, so that no conflicts or perceived inequity between colleagues may arise. Additionally, some officers started to complain about too many officers present in the departments during the pandemic due to the suspension of annual leave. While command and executive officers appreciated the burden sharing between all officers, LEAs should keep the number of staff on duty at a minimum and use the personnel reserves as back-up in case of high infection numbers (Brito et al., 2009). Thirdly, LEAs reduced the risk of infection by limiting the interaction with the public. In the officers' reports in the present study, those measures including focussing on the investigation of critical incidents or felonies only and expanding online reporting options or call centers mainly benefitted officers being on duty in departments. In the literature, there are also reports of measures that aim at protecting street patrol officers in the field, including suspending protocols that put people in custody or handling non-violent and non-emergency calls via telephone (Jennings & Perez, 2020). Additionally, dispatchers can be instructed to divert calls for service to public health services if a police response is not necessary. In case a police response is necessary, dispatchers could screen for COVID-19 symptoms of the caller to prepare the dispatched officers (Jennings & Perez, 2020). However, many of these measures come at the cost of regular crime investigation, which led to a loss of sense of purpose for some officers. Officers' concerns about the fundamental responsibility of police work should be acknowledged by the superiors to ensure job satisfaction.

Addressing internal communication, officers reported effective measures less frequently. Nonetheless, information provision emerged as a main theme requiring further coping resources. Officers reported to be stressed by an overload of ambiguous, rapidly changing and sometimes contradictory information, which led to uncertainty in action. Therefore, strong leadership is warranted that addresses this uncertainty. Milliard and Papazoglou (2020) recommend leaders to educate and regularly update their teams using valid knowledge from established organizations. As indicated by the officers' reports, LEAs should make use of the hierarchy, which was named as one organizational resource, by pooling and filtering information from various sources in a superordinate authority. Then, information containing relevant and clear instructions for action should be distributed to the different target groups within the authority. In their reports, officers mentioned FAQs, daily newsletters or help telephones as best practices.

In organizational crisis prevention, police training plays a central role as indicated by the negative association of feeling prepared through training with strain and by the officers' reports. Besides the request for training on health and safety precautions during a pandemic (Brito et al., 2009; Jennings & Perez, 2020), our results revealed that skills acquired in the regular police training, especially self-protection, communication and stress regulation, can be transferred to the context of a pandemic. Officers mostly rated situational response training as effective.

Confirming the effectiveness of situational response training, some officers asked for more training for exceptional situations. This is in line with the general request for more frequent and realistic police training (Di Nota & Huhta, 2019; Renden, Nieuwenhuys, Savelsbergh, & Oudejans, 2015). To ensure that the majority of the officers benefits from training experiences, transferability into real-world contexts can be achieved by training under stress (Nieuwenhuys & Oudejans, 2011) and following the recommendations of non-linear pedagogy (Körner & Staller, 2018).

3.2.3. Individual measures

As demonstrated by the large inter-individual variance in the statistical analyses, individual stressor appraisal and emotion regulation might outweigh governmental and organizational measures to cope with the pandemic. As officers are predicted to continue to deal with the stress caused by the pandemic in the upcoming months, it is important for departmental leadership to reduce stress as much as possible, and for officers to identify positive coping strategies (Stogner et al., 2020). While individuals are certainly required to engage in active coping themselves, LEAs can support their (vulnerable) members by educating on healthy coping strategies (Milliard & Papazoglou, 2020). For emotion-focused coping, reappraisal, reflection, distraction and social sharing have been identified as adaptive. For problem-focused coping, LEAs can reduce uncertainty by providing information or giving advice on how to handle the uncertainty, building on existing knowledge and skills officers have acquired in police training. Although officers reported to be more stressed by the uncertainty than the (long) working hours, LEAs should give officers enough resting hours and opportunities to engage in positive coping strategies (Milliard & Papazoglou, 2020). LEAs should provide professional psychological support and leaders should encourage officers' seeking of such programs (Rooney & McNicholas, 2020). However, these programs are often criticised as the hyper-masculine culture of the police discourages officers to seek external help. Therefore, programs that target positive coping skills through peer networks in partnership with clinicians (Papazoglou & Tuttle, 2018; Stogner et al., 2020) or in the standard training curriculum (Papazoglou & Andersen, 2014) are often recommended.

In sum, the police carries great responsibility in the effort to control pandemics. Therefore, effective management is crucial to protect officers' functioning, well-being, and health. Reducing officers' stress by increasing public awareness for the necessity of measures, providing sufficient PPE, reducing uncertainty by unambiguous information, preparing officers for exceptional situations, and strengthening their individual coping resources may be an effective approach to safely lead them through the pandemic without compromising officers' performance (Hope, 2016; Nieuwenhuys & Oudejans, 2017; Stogner et al., 2020) or well-being (McEwen & Stellar, 1993).

3.3. Strengths, limitations and further directions

Substantiating narratives about police stress, mental health, and resiliency (Jennings & Perez, 2020; Rooney & McNicholas, 2020; Stogner et al., 2020), this is the first study to provide empirical data on officers' stress experiences during the COVID-19 pandemic. The mixed-method approach allowed us to test hypotheses that could confidently be derived from the traditional stress research, but also to capture the novel stressors and the variety of coping resources due to the unprecedented state of a global pandemic. Major methodical strengths of the study are the longitudinal design and the inclusion of five different European countries. However, only 10% of the participants completed the questionnaires at three measurement points, which overidentifies linear trajectories. Given the missing data, the integration of random slopes in the growth curve model would have been based on a large proportion of estimated data. Therefore, we only included fixed effects in the models. To increase sample sizes, we encouraged the responsible person in each LEA to widely distribute the online survey among their accessible work force, resulting in limited control of the size, region and demographic characteristics in each subsample. As a consequence, geographic distribution over the respective country, types of LEAs (e.g., federal vs. national police) and demographic characteristics of participating officers differed among countries. Thus, caution must be taken in the interpretation of the results: Austria and Germany are overrepresented in the data, the representativeness of the sample in each country might be limited and cross-country differences might be (partly) attributable to demographic differences, as has been the case for sex and work experience in the statistical analyses.

The present study assessed officers' stress experiences and coping on duty and at the workplace. To reduce participants' burden based on questioning them, we used questionnaires originally developed for ecological momentary assessment. Therefore, findings might be limited by the use of single-item measures. To counteract the associated reliability concerns, we calculated summary indexes (i.e., strain, stressor appraisal, adaptive and maladaptive emotion regulation) when possible. Nevertheless, data might be biased by daily fluctuations since we did not control for potential daily confounding factors (e.g., off- vs. on-duty, type of the shift, timing in the shift, etc.). Finally, to receive authentic reports, officers provided their answers in their mother tongue. For coding, data units were analyzed in the respective language, but categorized into an English coding system. This procedure required coding by five different coders (four raters speak German and Dutch as their mother tongue, while one rater had advanced skills in Spanish), which might have resulted in biases in the categorization due to differences between the coders. Caution must be taken in the interpretation of the frequencies for each main category. We used the frequencies of the categories as a tool to identify the emerging main themes and patterns, but our main goal was to give voice to the officers and to get a full picture of officers' stress experiences during the pandemic.

Acknowledging the strengths and limitations, the results of the current study point in direction for further research. First, despite the longitudinal design, the study only captured a short period of the pandemic and epidemiologists already discuss second waves and future outbreaks. Although the present results demonstrate a medium stress level on average, the long-term impact should be monitored, as chronic stress can have tremendous health consequences (Allison et al., 2019; McEwen & Stellar, 1993). Second, the present study only assessed stress experiences through self-report. Future studies could advance our findings using physiological stress measurements, replicating studies conducted before the pandemic's outbreak for comparison (Stogner et al., 2020). Finally, the effectiveness of the implications suggested by our results should be evaluated in experimental designs (e.g., the effects of situational response training on stress regulation in various settings).

4. Conclusion

In the wake of the unprecedented situation, it was likely that the LEAs and police officers were caught unprepared for the potential mental stress that they would experience. However, overall, officers seemed to tolerate the stress with slight decreases over three months after the lockdown. Nevertheless, the large inter-individual variance in strain indicated that female officers with less work experience, feeling unprepared and engaging in negative maladaptive emotion regulation are at risk to develop negative health consequences due to severe work stress. Given the persistence of the pandemic and the warning of second waves, now is the time for LEAs to prepare the (vulnerable) officers for these situations. Our results suggest that this requires three primary paths: 1) Governments must ensure to enact unambiguous laws and increase public compliance through effective media communication, 2) LEAs must focus on being logistically prepared for viral outbreaks through stockpiling PPE, having policies for building personnel reserves in action, and establishing efficient internal communication channels, and 3) LEAs must provide officers with training to improve skills for positive coping with exceptional situations and stress. Risk of infection

and uncertainty were the major sources of stress. By being logistically prepared for an outbreak with PPE, personnel reserves and plans for altering policing strategies, officers should experience less risk of infection. Legislating and communication of unambiguous health safety policies and clear instructions for action should reduce officers' uncertainty and stress. Since it is impossible to completely remove stress from these types of situations, strengthening individual coping resources through training would help officers to deal with the stress they face without the side effects of negative health consequences.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jcrimjus.2020.101756.

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Supplementary Material

Supplement Table S1

Overview of free-response questions, main categories and subcategories used for the qualitative analyses.

	Item	Main Category	Category
Private Stressors	Apart from the COVID19 crisis, are you currently exposed to any extraordinary private stressors (e.g., infection or death of a relative, divorce)?	Caregiving Duties	(Nursing) Care of Relatives
			Animal Care
			Child Care
			Home Schooling
		Economic and Domestic Obligations	Errands/Grocery Shopping
			Financial Worries
			House Building
			Living Conditions
			Moving
			Renovation
		Health Concerns	Mental Disorders
			Own (Chronic) Disease
			Pregnancy/Birth
			Risk of Infection with COVID19
			Sleep Deprivation
			Stress
		Romantic Relationships	Conflicts
			Divorce
			Long-Distance Relationship
			Separation
		Social Distancing	
		Worries about Relatives	Pregnancy/Birth
			Relative's/Friend's Death
			Relative's/Friend's Disease
Main Tasks	Please give a brief description of your main activities and assignments on duty in the last week (e.g., patrolling, monitoring compliance with self-isolation requirements, traffic accidents).	Border Control	
		Corona Patrol	Compliance with Prohibition of Access/Residence
			Compliance with Social Distancing Regulations
			Control of Home Quarantine
			Covid Parties
			Delivery of Notifications about Home Quarantine
			Monitoring Closure of Businesses

			Patrolling in Critical Infrastructures
			Police Presence
			Vehicle Controls (to enforce social distancing regulations)
		Criminal Investigation	Analysis of Confiscated Data Media
			Analysis of Police Files
			Field Investigation
			Interrogation
		Emergency Call Taking and Dispatching	
		Management Tasks	Adminstration
			Data Maintenance
			Employee Supply
			Human Resources Planning
			Information Supply
			Material Procurement
		Off Duty	
		Office Service Tasks	Email Communication
			Informing Citizens
			Processing Police Reports
			Public Service
		Regular PoliceTasks	Arrest
			Burglary
			Crowds
			Dealing with Mentally Ill People
			Dispute Resolution
			Domestic Violence
			Fire
			General Police Assistance
			House Raids
			Identity Check
			Nuisance/Disturbance
			Official Acts of Foreign Law
			Physical Assault
			Property Protection
			Suicide
			Theft
			Traffic Accident
			Traffic/Vehicle Control
Work Stressors	Which circumstances and/ or operational tasks within the police work have particularly stressed you during the last week?	Leadership & Communication	Actionism
			Information Overload
			Lack of Empathy
			Lack of Internal Communication

Why were these circumstances/ tasks stressful?		No Clear Instructions for Action
		No Clear Responsibilities
	Operational Tasks	Administration
		Border Control
		Corona Patrol
		Informing Citizens
		Monitoring Compliance with Governmental Measures
		Unrelated
	Risk of Infection	Being a Risk of Infection for Others
		Civil's Intransigence
		Contact with Infected Civils
		Contact with Mentally Ill
		Ignorance about Health (COVID19) Status of Others
		Inability to keep Minimum Distance
		Increasing Number of Infected Colleagues
		Lack of Protection Equipment
		Risk of Own Infection
	Sense of Purpose	Increase of Domestic Violence
		Invalidity of Corona Patrol
		No Regular Criminal Prosecution
	Uncertainity about Future	
	Uncertainity in Action	Different Governmental Measures by Different Provinces
		Dynamics of the Situation
		Unfamiliar with Task
		Vague Legal Situation
	Working Circumstances	Acting Against Own Beliefs
		Boredom
		Compliance with Hygiene/Social Distancing Rules
		Group/Team Climate
		Media Coverage
		Oronasal Mask
		Overall Situation
		Sleep Rhythm
		Social Distance to Colleagues
		Time Pressure
	Working Hours and Annual Leave	Changing of Working Hours
		Long Working Hours
		Shift Roster

			Suspension of Annual Leave
Crisis Measures	Which crisis measures taken at short notice facilitate your police work during the COVID19 crisis?	Additional Authority for Action	Prompt Intervention (“Organmandat“)
			Clear Laws
			Legal Basis for Interventions
		Hygiene Measures	Spitting Protections (acrylic glass walls)
			Protective Equipment
			Telephone/Online Conference Calls
			Safety Distance in the Office
		Information Supply	Clear Instructions Regarding Governmental Measures
			Clarification of Legislative Decree Through Examples
			Regular Update of Information
			Training
			Filtered Information
			Central Source of Information
		Measures to Restrict Civil Contact	Online Police Services
			Changed Processes for Making Police Reports
			Less Public Service
			Governmental Measures for General Population
			Interrogations Restricted to Serious Offences
			Easier Travel to Work
			Home Office
			Adjustment to Shift Roster
			Leave of Absence from Duty/ Release from Duty
			Reducing Minimum Staff Numbers
		Others	
		Personnel Measures	Suspension of Annual Leave
			Scope for Action
			Increasing Staff Numbers
		Social Support	By Colleagues
			By Superiors
		Structural Adjustments	Task Force
			No Priority Actions
			Support by Armed Forces
		Unsatisfactory	

Crisis Prevention	Which crisis preparedness measures (e.g., training) have prepared you for your current work demands during the COVID19 crisis?	Off-Duty Training	Communication Skills
			First Aid Training
			Meditation/Yoga
			Other
			Paramedic Training
			Self-Study
			Stress Management
		Organizational Resources	Competence of Decision Making
			Flexibility
			Hierachy
			Internal Information/Task Force/Mails
		Police Training	Basic Training
			E2a
			First Aid Training
			Hygienic Training
			Keeping Distance for Self-Protection
			Radiation Protection Training
			Scenario-Based Training
			Understanding for Legal Regulations/Decrees
			Communication Skills
			General Psychology Knowledge
		Psychology	Stress Management
			Experience from Other Crises
			Experiences with Crowds/Large Incidents
		Work Experience	General Work Experience
Support	In which areas would you like to get more support? What measures could be taken to achieve this?	Compatibility of Family and Work	
		Corona Protection	Better Protection Equipment
			Hygiene Information
			Medical Checks
			More Protection Equipment
			Physical Segregation
			Protection of Officers' Families
			Testing
		Governmental Measures	Additional Governmental Measures
			Legal Certainity
			Standardised Procedure in all Provinces

	Clear Structure of Information
Information Provision	Long-Time Planning
	Pooling of Information Sources
	Specialised Training Courses
	Transparency
	Accelerated Implementation of Measures
Leadership Support	Appreciation/Acknowledgement
	Cooperation with Public Health Department
	Lower Administrative Burden
	Psychological Support
	Flexible Working Hours
	Increase in Personnel Strength
	Increasing Rest Periods
Personnel Adjustments	Less Home Office (no practical solution)
	More Home Office Possibilities
	Reducing Minimum Staff Numbers
	Salary Increase
	Technical Equipment for Home Office

Supplement Table S2

Mean and standard deviation (in brackets) of strain, stress appraisal, emotion regulation and preparedness at each measurement point in each country.

		Strain	Stress Appraisal	Adaptive Emotion Regulation	Maladaptive Emotion Regulation	Preparedness
Austria	t_1	3.72 (1.32)	4.12 (0.75)	3.81 (1.10)	3.14 (1.24)	2.87 (1.64)
	t_2	3.49 (1.34)	3.91 (0.75)	3.70 (1.12)	3.02 (1.23)	3.00 (1.71)
	t_3	3.37 (1.36)	3.77 (0.73)	3.70 (1.14)	3.05 (1.25)	2.89 (1.71)
	t_4					
Germany	t_1	3.97 (1.23)	4.31 (0.68)	4.69 (0.96)	3.75 (1.20)	2.50 (1.59)
	t_2	3.86 (1.36)	4.18 (0.70)	3.90 (1.04)	3.16 (1.28)	2.46 (1.44)
	t_3	4.05 (1.44)	4.21 (0.70)	3.82 (1.00)	3.22 (1.26)	2.52 (1.52)
	t_4					
Switzerland	t_1					
	t_2	3.08 (1.31)	3.89 (0.70)	3.61 (1.09)	2.75 (1.19)	3.13 (1.66)
	t_3	2.94 (1.21)	3.67 (0.74)	3.74 (1.09)	2.73 (1.12)	3.59 (1.70)
	t_4	2.86 (1.20)	3.61 (0.68)	3.52 (1.04)	2.74 (1.21)	3.26 (1.55)
Netherlands	t_1					
	t_2	3.29 (1.39)	3.86 (0.63)	4.42 (0.89)	3.00 (1.51)	2.91 1.65)
	t_3					
	t_4					
Spain	t_1					
	t_2	4.17 (1.44)	4.49 (0.68)	4.10 (0.83)	4.03 (1.16)	3.30 (1.78)
	t_3	3.51 (1.74)	4.18 (0.83)	3.89 (0.93)	3.76 (1.24)	3.58 (2.14)
	t_4	3.80 (1.85)	4.20 (0.85)	3.90 (0.44)	3.90 (1.27)	2.80 (1.99)

Note. All variables were assessed on a scale ranging from 1 to 7.

Supplement Table S3

Frequencies of perceived private stressors, main tasks, work stressors, effective crisis measures, effective crisis prevention and wishes for support across countries (in % of all coded answers).

	GER	AUS	SUI	NL	ESP
Private Stressors					
Caregiving Duties	**9.3**	**3.6**	**2.6**	2.8	0.9
Economic and Domestic Obligations	2.7	2.2	2.1	**8.2**	0.9
Health Concerns	3.9	3.3	1.9	**6.8**	**1.4**
Romantic Relationships	0.0	0.0	0.0	0.0	0.0
Social Distancing	0.0	0.0	0.0	0.0	0.0
Worries about Relatives	**8.9**	**5.3**	**6.1**	**6.8**	**10.5**
Empty/ No Answer	**75.2**	**85.6**	**87.3**	**75.4**	**86.9**
Main Tasks					
Border Control	0.0	3.0	0.0	1.3	0.0
Corona Patrol	**32.1**	**43.8**	**25.1**	**26.7**	**48.2**
Criminal Investigation	11.8	4.3	1.4	8.1	1.2
Emergency Call Taking and Dispatching	0.5	0.1	1.4	10.7	0.0
Management Tasks	**20.7**	**13.9**	**13.9**	0	**17.6**
Off Duty	1.1	0.2	1.0	1.3	1.2
Office Service Tasks	13.8	5.2	10	**17.3**	0.0
Usual Patrolling Service	**16.3**	**27.0**	**44.9**	**33.3**	**29.4**
Empty/ No Answer	3.7	2.5	2.2	1.3	2.4
Work Stressors					

Leadership Communication	14.0	10.8	3.2	8.8	3.3
None	**20.7**	**28.6**	**31.1**	**32.5**	**15.3**
Operational Tasks	1.7	3	**16.6**	6.3	**15.3**
Risk of Infection	**16.9**	**17.8**	**16.8**	**30**	**22**
Sense of Purpose	2.2	1.2	0.8	0.0	6.8
Uncertainty about Future	2.4	1.3	1.4	0.0	0.0
Uncertainty in Action	4.9	7.5	3.4	0.0	10.2
Working Circumstances	12.2	**11**	8.3	**12.5**	**18.6**
Working Hours and Annual Leave	10.7	9.1	5.3	7.5	1.7
Empty/ No Answer	**14.3**	9.7	13.1	2.4	6.8
Effective Crisis Measures					
Additional Authority for Action	0.5	2.1	4.2	2.5	5.4
Hygiene Measures	11.1	6.8	11.2	**11.4**	**39.3**
Information Supply	3.6	2.5	7.7	5.1	8.9
Measures of Restricted Civil Contact	12.4	**22.9**	**18.9**	1.3	8.9
None	**28.9**	**37.8**	**15**	**31.6**	5.4
Others	0.5	0.1	9.1	3.8	0.0
Personnel Measures	**22.4**	11.0	**19.7**	**35.4**	**17.9**
Social Support	0.9	0.3	0.0	0.0	0.0
Structural Adjustments	2.7	2.7	0.4	1.3	0.0
Unsatisfactory	1.1	0.8	2.0	0.0	0.0
Empty/ No Answer	**15.9**	**12.9**	11.8	7.6	**14.2**
Effective Crisis Prevention					
None	**41.3**	**51.8**	**35.4**	**59**	**28.9**

Off Duty Training	2.0	1.7	0.7	2.6	1.9
Organisational Resources	**11.4**	**12.6**	11.4	**12.8**	**11.5**
Police Training	10.7	10.6	**14.5**	6.4	**34.7**
Psychology	5.7	2.1	8.2	0.0	1.9
Work Experience	5.3	3.7	3.6	7.7	**11.5**
Empty/No Answer	**23.6**	**17.5**	**26.2**	**11.5**	9.6
Wishes for Support					
Compatibility of Work and Family	2.8	0.9	0.2	0.0	0.0
Corona Protection	**23.1**	**22.2**	**17.8**	**19.1**	**40.3**
Governmental Measures	3.1	8.1	6.6	2.4	8.1
Information Provision	14.3	**20.9**	**18.8**	**20.2**	**27.4**
Leadership Support	6.2	6.6	10.8	0.0	**14.5**
Personnel Adjustments	**16.7**	11.8	4.0	16.7	3.2
None	9.9	11.4	17.3	**32.1**	0.0
Empty/ No Answer	**23.9**	**18.1**	**24.5**	9.5	6.5

Note. GER = Germany; AUS = Austria; SUI = Switzerland; NL = Netherlands; ESP = Spain; numbers in bold represent the three most frequently mentioned categories.

Supplement Table S4

Supplementary Quotations of Police Officers for Main Tasks, Work Stressors, Effective Crisis Measures, Effective Crisis Prevention and Lack of Support During the COVID-19 Pandemic.

Main Tasks	More work with less personnel, as this was deducted for the so-called “corona patrols”. (female German officer, 52 years, t3) Emphasis on compliance with social distancing rules. Police work gets far too little attention! (male Austrian officer, 30 years, t2) Many conversations with the unsettled civil population: May I go for a walk, may I visit my parents? (male Austrian officer, 59 years, t1) I work on the street to avoid contacts with colleagues as much as possible. I ride alone so my existence on duty is lonely. I confront people with their behaviors and am surprised by people’s responses. (male Dutch officer, 53 years, t2)
Work Stressors	At the start of each shifts, a dozen mails must be read before the currently "right" actions can be applied. (male German officer, 29 years, t1) At present I am not able to meet the demands of the constant change of the existing regulation with corresponding short-term rescheduling in the service operation/ my actual task and the demands on it. No reliable statement or reachability of my superiors. (female German officer, 48 years, t3) "Compassion" with the population, the idea of being in the same boat with everyone. (male Austrian officer, 38 years, t1) Enforcement of measures that encroach on rights guaranteed by the Federal Constitution. I am an advocate and fighter for these rights. (male Austrian officer, 59 years, t1)
Effective Crisis Measures	None. The alternating service system would make more sense than group service. Besides, there are far too many officers on duty. (female Austrian officer, 26 years, t1) None, all measures give more actions, stress and often lack clarity. As an example: When do we wear the protective equipment? How well are we protected? What to do in case of a corona indication if someone has to be arrested anyway? (male Dutch officer, 24 years, t2) Fewer people, no events, closed shops and restaurants - hardly any operations besides the monitoring of measures (female Austrian officer, 40 years, t1) Very good informative approach of the government, clear rules and necessary tightening of measures. (male Austrian officer, 49 years, t1) The short-term introduction of the home office, which was unfortunately cancelled all too quickly. (female German officer, 36 years, t2) None of my colleagues belongs to this "illustrious circle" of those who (may) work in the "home office”. (male Austrian officer, 50 years, t1)

	Initially the shift model, this was very helpful now all sit on top of each other this is very bad. (male German officer, 29 years, t2) Work in small groups to avoid contamination and overlap. Make good work arrangements. Compensation of remaining hours. (male Dutch officer, 40 years, t2)
Effective Crisis Prevention	I don't know what has been taught about this kind of crisis situation... an invisible unstoppable virus has nothing to do with gunmen running amok and terrorist attacks. (female German officer, 31 years, t2) None, because it is an unforeseeable situation. (male Austrian officer, 52 years, t1) A minuscule commander training, apart from that nobody was really prepared for this. (female Dutch officer, 30 years, t_2) No professional; personal behavioural routines and stress regulation behaviours (sport etc.). (male German officer, 60 years, t_3) Orderly and anticipatory stockpiling of hygiene material, disinfection, oronasal masks. (male German officer, 37 years, t1) I see the most potential in dealing with information. In future, it should be possible to filter the information in question and only pass on what is absolutely necessary to the services. A flood of information, as has happened in recent days, places a heavy burden on officials and in no way increases the certainty of action or legal certainty. (male Austrian officer, 29 years, t1) Inclusion of scenarios such as the COVID19 crisis and related cooperation obligations for the police in basic police training (female Austrian officer, 22 years, t_1) Using police knowledge, knowledge of the current and most important laws, years of experience and common sense and not to forget competence in dealing with people, are the requirements in police service in general and also in the course of the current crisis. I have acquired these requirements in my age and during my many years of service. (male Austrian officer, 54 years, t1) Partly prepared in the course of the training of the operational unit, since it is trained how to deal with angry/nervous crowds. (male Austrian officer, 26 years, t1)
Wish for Further Support	Protective equipment has not been provided to us and hygiene equipment for our own location is also scarce and what is there, has almost all been purchased by ourselves and not obtained through the employer. (male Dutch officer, 37 years, t2) I believe that everyone involved, from superiors to grassroots officers, makes a significant contribution in this special situation. (male Austrian officer, 55 years, t2)

Appendix A2 – Manuscript 2

Note:
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Acute and Chronic Stress in Daily Police Service: A Three-Week N-of-1 Study

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Abstract

On duty, police officers are exposed to a variety of acute, threatening stress situations and organizational demands. In line with the allostatic load model, the resulting acute and chronic stress might have tremendous consequences for police officers' work performance and psychological and physical health. To date, limited research has been conducted into the underlying biological, dynamic mechanisms of stress in police service. Therefore, this ecological momentary assessment study examined the associations of stress, mood and biological stress markers of a 28-year-old male police officer in a N-of-1 study over three weeks (90 data points). Four times a day (directly after waking up, 30 minutes later, 6 hours later, before going to bed), he answered questions about the perceived stress and mood using a smartphone application. With each data entry, he collected saliva samples for the later assessment of salivary cortisol (sCort) and alpha-amylase (sAA). In addition, data was collected after six police incidents during duty. sCort – and also sAA – were not related to perceived stress in daily life and did not increase in police incidents. Regarding mood measures, deterioration of calmness, but not valence and energy was associated with perceived stress. The results suggest continued police service to constitute a major chronic stressor resulting in an inability to mount a proper response to further acute stress. As an indicator of allostatic load, psychological and biological hyporesponsivity in moments of stress may have negative consequences for police officers' health and behavior in critical situations that require optimal performance. Next, this research design may also become relevant when evaluating the efficacy of individualized stress management interventions in police training.

Key words: allostatic load, repeated hits, acute stress, salivary cortisol, salivary alpha-amylase, police officer

Acute and Chronic Stress in Daily Police Service: A Three-Week N-of-1 Study

Despite high levels of occupational stress due to frequent exposure to critical incidents and structural demands (Anderson et al., 2002), police officers are expected to act adequately, reasonably and moderately at all times, even in violent or life-threatening situations. For example, when an officer is called upon a case of domestic violence after a long nightshift, he or she is required to ignore the consequences of sleep deprivation, regulate his or her emotions to the physical threat and calmly resolve the situation with proportionate force. The constant demand for stress regulation in police service has already been shown to overstrain the basal functioning of physiological stress systems among officers (Allison et al., 2019; Planche et al., 2019). Although adaptive stress functioning is crucial for optimal performance in high-stress situations (Nieuwenhuys & Oudejans, 2017), it is unclear how these changes influence the officers' psychological and biological stress responsivity to critical incidents. A better understanding of acute and chronic stress responses during daily police duty and their underlying biological mechanisms is warranted to promote police officers' effective performance on duty, and their long-term health.

Given that police officers are confronted with a variety of stressors (Anderson et al., 2002), there is growing consensus that an allostatic load model may apply to police work (e.g., Allison et al., 2019). *Allostasis* refers to the active physiological process of maintaining homeostasis in face of perceived or actual threats (Mc Ewen & Stellar, 1993). Under acute stress, the nervous system mobilizes the individual's capacities to deal with the environmental demands. Associated allostatic responses are the activation of the fast reacting sympathetic-adrenomedullary (SAM) system with the release of catecholamines and the slower hypothalamo-pituitary-adrenal (HPA) axis (McEwen & Stellar, 1993) with the release of glucocorticoids, mainly cortisol. They are adaptive when rapidly mobilized and terminated, so that systems return to baseline levels of cortisol and catecholamine secretion. However,

frequent exposure to critical incidents and prolonged exposure to structural demands can lead to a state of *allostatic load* or *overload*. Eventually, this state of chronic stress ("wear-and-tear") leads to dysregulation of the normally protective stress systems, i.e., hypoactivity of the HPA axis, sympathetic overdrive and vagal withdrawal. Dysregulation ultimately results in vulnerability to diseases and psychological dysfunctions through maladaptive effects on brain plasticity and metabolic, immune, and cardiovascular pathophysiology (Herman, 2013).

In line with the allostatic load model, police officers could be regarded as chronically stressed, whose basal functioning of physiological stress systems have been overstrained. This assumption of HPA axis dysregulation is supported by findings of heightened diurnal cortisol levels, lack of physiological recovery from stress, and flattened diurnal and cortisol awakening response (CAR) slopes among police officers. Police officers had higher diurnal cortisol levels than the general population (Planche et al., 2019), whereby higher serum cortisol levels were positively associated with perceived occupational stress in the past month (Walvekar et al., 2015). Cardiovascular data showed that police officers did not fully recover from critical incident stress before leaving the shift (Anderson et al., 2002). Allison and colleagues (2019) observed persistent elevations of circulating cortisol even until bedtime. These heightened cortisol levels seem to be accompanied by flattened diurnal rhythms, which were associated both with perceived stress of critical incidents (especially physical danger stress; Allison et al., 2019; Violanti et al., 2017) and organizational stressors (i.e., lack of support, and shift work; Allison et al., 2019; Charles et al., 2016). Particularly, shift work has been discussed as a major organizational stressor directly altering HPA functioning. Short- and long-term night shifts have been associated with lower CAR (Fekedulegn et al., 2012; Wirth et al., 2011) and shallower daily cortisol slopes (Charles et al., 2016) among officers. Disrupted sleep as a result of shift work (Fekedulegn et al., 2012; Gerber et al., 2010) and exposure to critical incidents (Bond et al., 2013) is proposed as a potential mechanism that

temporarily increases the activity of the HPA system and in the long run, affects the reactivity of these systems to other stressors (Meerlo et al., 2008). In this sense, poor sleep quality was associated with diminished awakening cortisol levels and dysregulated cortisol patterns among inactive officers (Fekedulegn et al., 2018). These findings strengthen the assumption of police service as a relevant chronic stressor resulting in high, flattened diurnal cortisol profiles that put officers' health at risk (Adam et al., 2017; Violanti et al., 2018).

Besides the dysregulation of the diurnal cortisol profiles among police officers, there is an ongoing debate whether chronic stress also influences the reactivity to acute stress, especially in high-stress populations (Zänkert et al., 2019). Hyporesponsivity describes the severely attenuated hormonal response of the HPA axis to stressors. Police officers demonstrated pronounced psychological and cardiovascular stress reactivity to critical incidents, both in experimental studies (Giessing et al., 2019; Strahler & Ziegert, 2015) and on duty (Andersen et al., 2016; Anderson et al., 2002; Baldwin et al., 2019; Hickman et al., 2011). However, studies on neuroendocrinal stress responses, namely salivary cortisol (sCort) and alpha-amylase (sAA) – reflecting HPA axis and SAM activity, respectively (Strahler et al., 2017) – have primarily been conducted in laboratory settings with inconsistent findings. While some studies found increased sCort and sAA levels in response to simulated scenarios (Groer et al., 2010; Taverniers & de Boeck, 2014), other studies could not observe a sCort response despite increases in self-reported anxiety (Arble et al., 2019; Giessing et al., 2019; Strahler & Ziegert, 2015). Thus, police officers' high, flattened diurnal cortisol profiles might result in blunted sCort responses to critical incidents, while psychological and SAM responses seem to be unaffected. Maladaptive stress reactivity to critical incidents might impair police officers' performance in these situations, putting their and civilians' safety at risk (Giessing et al., 2019). Also, increases in this marker do not necessarily reflect acute psychological responses (Campbell & Ehlert, 2012). From the current understanding, this can be partly

attributed to different dynamics of the systems (Schlotz, 2019). Thus, an important issue in appropriate assessment designs for studying within-subject associations is the timing of the saliva sample relative to the assessment of stress (Schlotz, 2019).

Despite the importance of adaptive stress functioning and optimal performance of police officers in critical incidents, little is known about their stress responsivity during daily police service. Although laboratory studies allow for standardization of stressors, generalization to real life stress conditions is limited. Field studies featuring momentary collection of biological stress marks in natural settings are predicated on the notion that more information is needed about psychobiological responses to stressors in daily life to better understand the mechanisms through which stress leads to psychological, physical, and behavioral disorders. Ecological momentary assessment involves repeated sampling (usually multiple times during a day across several days) of current experiences, behaviors, and physiological states in real time and natural environments. Therefore, it is possible to study dynamic relations among stress variables of interest with a maximum of ecological validity, a minimum of recall bias and high-resolution information on within-individual variability (Trull & Ebner-Priemer, 2013). Reported variance components of daily life salivary cortisol assessment show large variability within individuals between assessments (instead of between-subject variability), even when accounting for individual and day-specific circadian trends (Schlotz, 2019). Consequently, intensive longitudinal approaches should focus on idiosyncratic associations between officers' psychobiological stress responses to critical incidents and organizational stressors. The N-of-1 design is suggested as useful design for examining within-person variability in cognitions, physiological outcomes, and behaviors (McDonald et al., 2017). The advantage of this design is that it allows to significantly increase the usually suggested number of five assessment days (Schlotz, 2019), which is particularly recommended if the research question is focused on within-subject variability. Since the

power of N-of-1 studies is determined by the number of repeated observations, it is possible to satisfy objectives with just one individual (Kwasnicka et al., 2019). Strahler and Luft (2019) used a longitudinal N-of-1 design and confirmed the potential of this design to monitor the dynamic, idiosyncratic responses in the high-stress setting of a ballroom dancer. While sCort and sAA were markedly increase in response to competitions, perceived stress in daily life was not related to increases in sCort, but to reduction in well-being. Following their research design, we examined time-varying relationships of stress, mood and salivary stress markers (i.e., sCort and sAA) of a male police officer during his daily life. In line with previous findings, we expected a high, flattened daily sCort profile. In moments of acute stress, we expected a deterioration of mood and increase in sAA, while no sCort response was expected due to an allostatic-load induced HPA axis hyporesponsivity.

Method

All procedures were conducted according to the declaration of Helsinki. The study design was approved by the ethics committee of the Faculty of Behavioral and Cultural Studies, Heidelberg University, Germany. The police officer gave written informed consent and approved the final version of this manuscript.

Participants

A German male patrol police officer (28 years, 27.7 kg/m^2) participated in this study. He was recruited by his department's superior, whose department was chosen to participate in the study by the responsible project coordinator in the law enforcement agency. He has worked for a police department in a big German city (> 500,000 inhabitants) for four years. His shift schedule consisted of 4-day rotating shifts (day, afternoon, night and free shift) of 10 to 12 working hours. He reported to be a non-smoker and stated no chronic physical or mental health problems at the start of the study. He lived in partnership with no children.

Data were collected throughout a 3-week period (mid-September to beginning of October 2019) covering ten on- and eleven off-duty days. Overall, there were 21 days of measurement with a total of 90 samples.

Study design

The police officer collected self-report data (mood, stress) and saliva four times a day for three weeks. The first sample was collected right after awakening while still in bed (*awakening*), and the second sample 30 minutes later (*+ 30 min*). Two further samples were collected six hours after awakening (*+ 6 h*) and right before going to bed (*bedtime*) to cover the whole day (total data points = 84). Due to the shift work hours, time points of sampling varied across the days. In addition, the police officer was instructed to collect at least one event-related sample in each shift after subjectively experienced stressful police incidents (n = 6; n = 2 appearing in the same shift). The officer collected the samples after the events, as soon as his police duties allowed sampling. Consequently, these events do not cover all incidents during his shift, but a sample that allowed sample collection without interference with his job in a reasonable framework.

Data collection procedures

Trait Questionnaires. To evaluate the police officer's trait anxiety, dispositional self-control, physical activity status and mental health at study start, we employed the German versions of the State-Trait Anxiety Inventory (STAI-T: Spielberger et al., 1983), the Self-Control Scale (SCS-K-D: Bertrams & Dickhäuser, 2009), the Physical Activity, Exercise, and Sport Questionnaire (BSA; Fuchs et al., 2015), and the Short Form Health Survey (SF-36; Morfeld et al., 2011). Additionally, we assessed the policer officer's chronic stress level (Perceived Stress Scale; PPS; Klein et al., 2016) and well-being (World Health Organisation-Five Well-Being Index; WHO-5; WHO, 1998) prior to the start of the study and retrospectively for the study period.

Electronically aided momentary assessments. To assess current mood and stress, the police officer completed an electronic diary on his own smartphone by means of the application movisens XS (version 1.5.0; movisens GmbH, Karlsruhe, Germany). An alarm (except for the awakening and bedtime sample which was triggered by the police officer) reminded the police officer to start the query and displayed questions and response options on the screen.

A six-item short version of the German Multidimensional Mood Questionnaire (Wilhelm & Schoebi, 2007) was used to measure the police officer's current affective state. Three bipolar scales represent *valence*, *energy*, and *calmness* [tired–awake (E+), content–discontent (V–), agitated–calm (C+), full of energy–without energy (E–), unwell–well (V+), relaxed–tense (C–)]. Answers were given by moving a slider from the start position 0, at the left end of a scale, to the position that corresponded best to the current state (maximum position 6). Wilhelm and Schoebi (2007) demonstrated the structural validity, sensitivity to change and reliability of this short scale. For analyses, values were transformed to range from 1 to 7 and data from three items (i.e., V–, E–, C–) were reverse coded. Average scores were calculated for valence (V), energy (E) and calmness (C).

Perceived stress was measured using the single item „At the moment, I feel stressed out" rated from 0 (*not at all*) to 6 (*very*). For analyses, values were transformed to range from 1 to 7.

For the event-related samples, the officer briefly stated which kind of call for duty he had encountered, whether weapons and use of force were involved. Additionally, he rated perceived stress, whether he perceived the situation as challenging, controllable, and threatening, and how satisfied he was with his performance on a scale from 1 (*not at all*) to 5 (*very*). The use of emotion regulation strategies was assessed by six items, each representing one emotion regulation strategy (Brans et al., 2013): „I have calmly reflected on my feelings"

(reflection), „I have changed the way I think about what causes my feelings“ (reappraisal), „I couldn´t stop thinking about my feelings“ (rumination), „I have talked about my feelings with others“ (social sharing), „I have avoided expressing my emotions“ (expressive suppression), and „I have engaged in activities to distract myself from my feelings“ (distraction). Additionally, we asked for acceptance („I have accepted it“). Each item was rated on a 5-point scale from 1 (*not at all*) to 5 (*very*).

Salivary stress markers. Salivary samples were collected using Salivette sampling devices (Sarstedt AG & Co, Nümbrecht, Germany). Sampling time was exactly 1 min during which the participant had to chew the cotton swabs as regularly as possible. The participant was instructed to not brush his teeth, and to not eat and drink (except water) 30 min prior salivating. On duty, he stored the saliva samples in a cooling bag, until they could be stored in the refrigerator at the end of each collection day. After samples had been returned to the study team, they were transported to the laboratory and stored at – 20 °C until further analyses. Biochemical analyses were conducted by the Steroid Laboratory of the Institute of Pharmacology, Heidelberg University, Germany. After thawing, saliva samples were centrifuged at 3000 rpm for 5 min, which resulted in a clear supernatant of low viscosity. Fifty microliters of saliva were used for duplicate analyses.

Free cortisol levels were measured using a commercially available immunoassay (IBL International, Hamburg, Germany). Intra- and interassay coefficients of variation were below 6 % and 15 %, respectively.

Salivary alpha-amylase (sAA) levels were measured using the analyzer ADVIA Chemistry XPT (Siemens, München, Germany) and the reagents #03031177 (Siemens, München, Germany). Saliva was diluted 1:200 using 0.9% saline solution. The method used ethylidene blocked p-nitrophenyl maltoheptaoside as substrate. The indicator enzyme a-glucosidase was used to release p-nitrophenol. The terminal glucose of the substrate was

blocked by indicator enzymes to prevent cleavage and was measured at 410nm. Inter- and intra-assay coefficients of variability for the assay were below 2%.

Statistical Analyses

Descriptive Data. Means of trait questionnaires were computed and compared with published norms. Means and standard deviations of repeatedly measured data were also determined. Due to the small sample size of event-related data and unequal distribution over testing days, it has not been included in the main analyses of dynamic relationships and was reported as descriptive data of each case.

Missing Data. Missing data was imputed using multiple imputation. Following the recommendation of Bodner (2008), it was set to create 15 data sets, which equals the highest percentage of missing data in the current study (see below). Thus, the following stages of analysis were carried out on each of the 15 data sets separately and the subsequent results were then combined to create pooled coefficients. SPSS 26.0 is able to do this for means, standard error, and in multiple regression, values of B and standard error and associated p-values, and others. For statistics in our analysis that SPSS 26.0 does not provide pooled coefficients for (i.e., adjusted R^2 and associated p-values) the mean of each statistic produced from the 15 datasets was taken.

As different units were used for self-report and biological data, data were transformed into z scores to express data onto a common scale. Means and standard deviations in text and figures are reported in original units for ease of comprehension.

Comparison of daily averages between on- and off-duty days and police incidents. Daily averages of self-reported and physiological data were compared on off- vs. on-duty days. To assess acute stress reactivity, self-reported and physiological data of police incidents were compared to daytime averages (mean of 3rd and 4th sample) using Mann-Whitney U test for independent samples. Of note, the Wilcoxon-signed-rank test would be the appropriate

non-parametric statistical test to compare repeated measurements of a single sample. However, this analysis was not feasible due to the large differences in number of time-based samples and number of event-related samples. Since the dependency of the samples were neglected in these analyses, the findings should be considered preliminary and caution should be taken when interpreting them.

Dynamic Relationships between variables. Statistical analyses regarding dynamic associations were carried out following the guidelines of McDonald and colleagues (2020). First, to assess time trends in the predictor or outcome variables a standard linear regression model was fitted for perceiv*ed stress* (as predictor), *valence, energy, calmness*, sCort and sAA (as outcome variables), respectively. Secondly, time series data may contain periodic variation (i.e., cycles that repeat regularly over time). In the current study, it was suspected that there might be an association between the variables of interest and measurement occasion as well as work shift (no duty vs. day shift vs. night shift). The existence of these patterns was assessed by fitting standard linear regression models, respectively. If a significant time trend or periodic pattern was identified, the respective variable was included in the final dynamic regression model.

Predictor and outcome variables were tested for serial dependency using autocorrelograms. A maximum time lag of 8 was applied to allow a 2-day cyclic pattern to be observed, if present. In case of significant autocorrelation in excess of 95% confidence intervals, a pre-whitening procedure was performed (see McDonald et al., 2020, pp. 43-46). Plots of partial autocorrelation were examined to determine the significant order of autocorrelation (e.g., first order, where current observation is dependent on that of preceding observation, fourth order where current observation is dependent on yesterday's observation at the same measurement occasion). A new variable was then created, lagged by the appropriate number of measurement occasions. This lagged variable was regressed onto the

original series; the unstandardized residuals became the new pre-whitened variable, which was checked to confirm absence of autocorrelation. Pre-whitened variables were included in the respective dynamic regression model. Additionally, the effect of past lags of the predictor *perceived stress* on the outcome variables sCort, sAA, valence, energy and calmness was checked using linear regressions.

To investigate the associations between *perceived stress* and mood as well as the salivary markers, dynamic regression analyses (Vieira et al., 2017) were conducted for sCort, sAA, valence, energy and calmness, respectively. If significant time trends, periodic patterns, or lagged predictors were identified throughout the process, the respective variables were entered in the dynamic regression model. To account for alpha error cumulation, a Bonferroni-correction was applied for mood scales.

Results

Trait characteristics

The police officer reported higher dispositional self-control (SCS score = 47) than the norm sample (M = 39.85, SD = 8.61, Tangney et al., 2004) and a sample of police recruits (*M* = 44.42, *SD* = 7.41, Giessing et al., 2019) and lower trait anxiety (STAI-T score = 34) compared to the norm sample (*M* = 36.7). However, with four years of working experience, the officer had slightly higher levels of trait anxiety compared to a sample of similar-aged police officers with more years of work experience (*M* = 29.3, *SD* = 6.5; nine years of work experience; Landman et al., 2016).

Perceived health-related quality of life was within the average (SF-36: physical functioning = 100, role physical = 100, bodily pain = 84, general health = 92, vitality = 60, social functioning = 100, role emotional = 100, and mental health = 96; Morfeld et al., 2011). Physical activity scores during leisure time were above average (121.5 min/week), same was true for sport activity scores (167.5 min/week; Fuchs et al., 2015). Notably, the policer officer

reported to engage in “rather more” (3 on a scale from 0 to 4) moderate activity on duty.

Chronic stress levels were slightly higher during the study (PSS score = 8) than prior to the study (PSS score = 4), but still very low when compared to age-appropriate norms (Klein et al., 2016). Subjective well-being was constantly high before and during the study (WHO-5 score = 64 and 68, respectively).

Missing data and plausibility check

Data were reviewed for completeness, compliance, and plausibility. The police officer dismissed or ignored four saliva samples (4.8%; one sample 30 min and three samples 6 h after awakening) and forgot to collect two bedtime samples (2.3%). Due to a spontaneous weekend trip, he did not collect five consecutive samples (6.0%; starting with a sample 6 h after awakening until the sample 6 h after awakening the next day). Due to application malfunction, the police officer took three samples (3.6%) by triggering data collection himself. Three saliva samples went missing (3.6%; one sample 30 min and two samples 6 h after awakening). sCort concentration was below the detection threshold (< 0.41 nmol/L) in six bed time samples (7.1%). Since sCort levels are expected to be low before bed time, these values were set to 0.41 nmol/L and included in the analyses (for comparison, the average value of the detectable bed time samples is 2.57 nmol/L ± 2.98). However, it must be acknowledged that nine of 21 bedtime samples (three completely missing, six set to detection threshold) were estimated. Outlier analysis showed n = 2 single sAA scores to be extreme values (three interquartile ranges above 3rd quartile). These scores (297 U/mL and 179 U/mL, respectively) were considered possible and plausible, and thus included into the data analyses.

Time points of sampling

On average, the first sample was provided at 09:46 hours (range: 04:32 to 14:02 hours). The large range is attributable to the alternating work shifts and the accompanying changes in sleep/wake times. The second sample was taken about 30 minutes later (*M* = 10:22

hours, range: 05:14 to 15:05 hours) indicating a high compliance rate (36.10 ±14.49 minutes). The third sample and fourth sample were collected at 16:24 hours (range: 10:32 to 22:48 hours) and between 21:30 and 07:06 hours, respectively. During duty, sampling times were quite variable (M =15:42 hours, range: 07:14 to 22:22 hours).

Comparison of daily averages between on- and off-duty days and police incidents

Descriptive data of mood (valence, energy, and calmness), stress, and salivary measures can be found in Table 1. Importantly, the officer underutilized the full scale for perceived stress (range: 1- 5), reporting that he felt stressed (< 5) at only two occasions. sCort and sAA showed their typical daily rhythm with a rather flattened CAR (computed as difference between the first and second sample with an average absolute increase of 1.83 nmol/L within the first 30 min after awakening) compared to normal values (average absolute increase of 7.84 nmol/L; Wüst et al., 2000; also see Miller et al., 2016). Figure 1 illustrates all values of sCort (top) and sAA (bottom) throughout the study.

There were no significant differences between daily averages on sCort, sAA, valence, energy, calmness or stress on off- vs. on-duty days (all Mann-Whitney U $p > .37$, see supplementary material Table S1).

A detailed description and descriptive data of each incident can be found in Table 2. The concentration of the incident sCort (4.16 ± 1.93 nmol/L) and sAA samples (89.57 ± 50.17 U/mL) did not significantly differ from the daytime average (sCort: 2.63 ± 2.03 nmol/L; sAA: 112.28 ± 46.20 U/mL; Mann-Whitney U $p > .144$). Perceived stress during incidents (3.83 on a scale from 1 to 7) did not significantly differ from the daytime average (3.05 on a scale from 1 to 7; Mann-Whitney U $p = .011$). In incidents, calmness significantly decreased (4.58 on a scale from 1 to 7) compared to the daytime average (6.21; Mann-Whitney U $p = .003$). The officer reported slightly more negative mood during incidents (6.17 on a scale from 1 to 7) than during daytime (6.45 on a scale from 1 to 7), but the difference failed to reach

significance (Mann-Whitney U $p = .059$). Energy did not significantly differ between incidents (6.00 on a scale from 1 to 7) and daytime (5.33, Mann-Whitney U $p = .188$).

For emotion regulation, the officer mainly used the strategies of reflection and acceptance (5 on a scale from 1 to 5 in $n = 4$ incidents). He never used distraction, expressive suppression or reappraisal as emotion regulation strategies. He seldomly ($n = 2$) reported social sharing and rumination.

Dynamic Relationships

The fitted standard linear regression models did not identify a significant linear time trend in *perceived stress* ($R^2 = .03$, p = .226), valence ($R^2 = .03$, $p = .217$), calmness ($R^2 < .01$, $p = .646$), energy ($R^2 = .01$, $p = .580$), sCort ($R^2 = .03$, $p = .172$) and sAA ($R^2 = .03$, $p = .226$), indicating that those variables did not change throughout the 3-week assessment period.

For periodicity, measurement occasion significantly predicted sCort ($R^2 = .44$, $p < .001$) and sAA ($R^2 = .12$, $p = .002$), thereby confirming their daily rhythms. However, measurement occasion did not significantly predict the self-reported measures (all $R^2 < .02$, all $p > .249$). Work shift did not significantly predict salivary markers and self-reported measures (all $R^2 < .02$, all $p > .202$; for all coefficients please refer to the supplementary material Table S2).

sCort, sAA, valence and energy were autocorrelated (see Table S3). Significant partial autocorrelations were found in sCort (lag 2, 3 and 4), sAA (lag 2 and 4), valence (lag 1) and energy (lag 2, 4 and 5; see Table S4) and thus, were followed by the pre-whitening procedure described above. Subsequent autocorrelograms confirmed the absence of autocorrelation after this procedure (please refer to Table S5). Past lags of the predictor *perceived stress* did not predict any outcome variable (see Table S6).

Results of all dynamic regression models can be found in Table 3. *Perceived stress* significantly predicted calmness at the concurrent measurement occasion (B = -0.68, 95%CI =

-0.88 – -0.48), but not energy, valence of mood, sCort and sAA. sAA and energy were predicted by the respective value of the previous day (i.e., Lag 4), reflecting the stability of the daily rhythm. Additionally, valence is predicted by valence of the previous measurement occasion (i.e., Lag 1).

Discussion

To our knowledge, this was the first ecological momentary assessment study to examine stress-related dynamics in mood and salivary stress markers in the daily life of a police officer. While larger cross-sectional studies have provided much evidence for the presence of allostatic load and dysregulated physiological stress systems in police officers, the main goal of the present study was to capture intra-individual, dynamic relationships between self-reported and biological stress responses to acute and chronic police stressors. Our study demonstrated (a) that the police officer showed – on average – a typical daily sCort pattern with overall high levels and a rather flattened CAR, (b) that, as hypothesized from the allostatic load framework, sCort was not associated with perceived stress, (c) that, contrary to the expectations, sAA was not related to perceived stress and (d) that only deterioration in calmness (but not valence and energy) was associated with perceived stress.

The study suggests that the officer has experienced allostatic load, a state of exhaustion of stress-responsive systems due to the cumulative "wear and tear" on the body caused by repeated and chronic stress in police service. Although the officer reported rather low levels of stress, overall sCort concentration was higher than the general population – comparable to other frontline officers (Planche et al., 2019). This discrepancy between psychological and biological stress responses is not uncommon in the literature (Campbell & Ehlert, 2012), particularly for police officers who might be resistant to admit experiences of stress (Di Nota & Huhta, 2019). At the same time, officers are prepared to be confronted with high-stress situations (e.g., exposure to battered or dead children, killing someone or fellow

officer killed in the line of duty). Although the probability of occurrence is small (Violanti et al., 2017), the officer might just have left room on the scale in case he encountered any of these situations during the assessment. Given the limitations of self-reports, multimethod approaches combining psychological and biological assessments are crucial in evaluating the impact of stress on police officers.

The CAR appeared rather attenuated compared to normal values (Wüst et al., 2000; also see Miller et al., 2016), which nevertheless, fits a great body of police literature on flattened diurnal cortisol slopes (Allison et al., 2019; Charles et al., 2016; Violanti et al., 2017). Together, the results are in line with the meta-analysis of Miller and colleagues (2007). They found that ongoing physically threatening, uncontrollable and traumatic stress – likely to be experienced by police officers – elicits high, flat diurnal profiles of cortisol secretion. They described a pattern of slightly lower morning output, but higher secretion in the afternoon/evening, leading to greater total daily hormone output. They argue that a persistently elevated HPA activity is adaptive in light of an ubiquitous potential for threat, since the system's hormonal products facilitate cognitive, metabolic, and behavioral adaptations to the stressor (Miller et al., 2007). When threats are constantly present, the organism cannot afford a diurnal rhythm, in which hormonal availability decreases during the day (Miller et al., 2007). While this might be adaptive for temporarily limited exposure to traumas (such as combats), police officers are likely to experience these high, flat diurnal profiles throughout their entire career putting them at risk to develop serious health conditions (Adam et al., 2017). Although the present officer having a relatively short work experience of four years reported to be healthy (as indicated by the self-reports on SF-36), longitudinal research with police officers suggests a link between physiological dysregulation and health problems eventually (Violanti et al., 2018, 2020). Likewise, daytime sAA concentrations of the police officer were considerably higher than in other high-stress populations, when

comparing similar measurement points across studies (Strahler & Luft, 2019; Wingenfeld et al., 2010; but see Liu et al., 2017b), which supports the assumption of a high level of general activation and arousal (Strahler & Luft, 2019). This might be particularly critical since the finding of no significant differences between daily averages on sCort, sAA, stress or mood might hint at failure to recover, as suggested by other research (Allison et al., 2019; Anderson et al., 2002).

In the present study, the high basal sCort and sAA levels appeared to be accompanied by a psychobiological hyporesponsivity to acute stressors. Confirming our hypotheses, sCort was not higher after critical incidents than usually during the day. Additionally, there was no significant association between momentary stress and cortisol, suggesting that sCort did not increase in moments of perceived stress. Contrary to the hypotheses, sAA was not related to momentary stress and did not increase in response to police incidents. We only expected the HPA function to be altered by allostatic load with intact SAM functioning in response to acute stress. However, sAA activity under chronic stress is less well-studied with heterogenous findings on basal sAA output (Berndt et al., 2012; Strahler & Luft, 2019; Wingenfeld et al., 2010). Typically, an increase in cortisol and alpha-amylase in response to acute stress is found in studies with healthy, non-stressed participants (e.g, in response to the Trier Social Stress Test, for a recent meta-analysis: Liu et al., 2017a). One methodological explanation for the lacking response might be the timing of the saliva collection relative to the corresponding assessment of stress. Although peaks in sCort occur approximately 15 min after stressor onset (Schlotz, 2019), a review of studies showed that concurrent assessments of subjective stress and sCort (as conducted for time-based sampling in the present study) is equally effective. Event-based sampling in the present study was – in most cases (n = 4) – delayed by 10 to 45 min, which is considered appropriate to capture cortisol peaks and reliable retrospective self-report data (Schlotz, 2019). However, the delayed sampling might

explain the missing response of sAA to incidents, as sAA is a marker for the fast-responsive autonomic stress response. While sAA levels in response to laboratory police simulations are greater than the officer's sAA reactivity to police incidents (e.g., Giessing et al., 2019; Strahler & Ziegert, 2015), they do resemble officer's sAA levels during the day (i.e., 6 h after awakening) when he was likely on duty. Nevertheless, one major limitation of the current study is that no *very stressful* event (rating > 6 on the perceived stress scale ranging from 1 to 7) occurred during the assessment. Therefore, the missing psychobiological stress responses might be explained through the lack of stressful events. However, two of the six critical incidents required use of force and additional two potentially involved the confrontation with injured or dead persons, which was rated as a major stressor in a sample of US officers (Violanti et al., 2017). Therefore, considering the findings as valid, they are in line with first reports on blunted cortisol responses of police officers to acute incidents (Arble et al., 2019; Giessing et al., 2019; Strahler & Ziegert, 2015). While cortisol hyporesponsivity has also been found in individuals with high levels of chronic stress, burnout and exhaustion (for an overview see Zänkert et al., 2019), clearly, more research is warranted to understand the consequences of chronic stress on sAA activity.

Psychobiological hyporesponsivity might have tremendous implications for the daily police work: While flattened diurnal sCort slopes have already been identified as a potential key mechanism to cause health impairments in the presence of social stress (Adam et al., 2017; Violanti et al., 2018), it is still unclear how hyporesponsivity impacts officers' long-term health. Given that an acute stress response adaptively mobilizes the body to cope with the stressor, blunted responses might also prevent police officers from effective functioning in critical police incidents, in which optimal performance is crucial for their and civils' safety. In a high-fidelity simulation of a domestic dispute, police recruits with greater sCort release showed higher levels of performance (Regehr et al., 2008). In addition, other studies suggest

that police performance might not be directly impaired by elevated stress levels. In case of effective self-control, police officers could maintain performance even in high stress situations despite elevated stress responses (Giessing et al., 2019; Landman et al., 2016). Given the signs of biological dysregulation in police officers, police training should include education about the potential mental and physical health effects of exposure to acute and chronic stress and enhance the acquisition of adaptive coping skills throughout the entire career, from recruit training until retirement (for a practical guide see Papazoglou & Andersen, 2014).

Regarding the officer's psychological stress reactivity, we could only partly confirm the relationship between stress and measures of well-being (Doerr et al., 2015; Schlotz, 2019; Strahler & Luft, 2019). The officer felt less calm in moments of perceived stress, but he did not report a more negative mood or less energy. Still preliminary, these results may hint at a certain psychological resistance to stress that the job as a police officers may confer. Certainly, better momentary mood in daily life is linked to global life satisfaction and long-term health benefits (Smyth et al., 2017). However, since other studies have found positive associations between sCort and deterioration of mood (summarized in Schlotz, 2019), the officer's lack of psychological response to stress corresponds well with the blunted sCort response. In this case, it remains speculative if the lack of stress responsivity is adaptive or maladaptive, especially during critical incidents. In contrast, the officer might have not reported stress responses, because he had already engaged in efforts to regulate those unwanted thoughts and emotions. He reported to mainly use reflection and acceptance as emotion regulation strategies. While these self-regulation processes seem to be effective in reducing unwanted emotions, it remains unclear if they might be counter-productive for performance in high-stress situations. In police settings, acceptance was related to maintenance of performance despite emotional stress responses (Landman et al., 2016).

However, engagement in reflection might reduce goal-directed attention and therefore, impair performance (Giessing et al., 2019; Nieuwenhuys & Oudejans, 2017).

A clear strength of the current study is the use of the ecological momentary assessment during daily police service. It adds to the limited literature on police officers' stress reactivity in real life (Anderson et al., 2002; Baldwin et al., 2019; Hickman et al., 2011) by advancing the understanding of within-person variability of psychological and biological stress reactivity to acute and chronic stress. The integration of salivary stress markers is an additional important advancement for stress research in the police context. As we have shown, the ability to capture biological and behavioral data in the field and during life is feasible in the police service. Exploiting these methods will allow to further explore the association of biomarkers and factors relevant to long-term health and work performance. In this case, future studies should ensure that their sampling design allows to capture stressful police incidents. Very little is known about optimal stress levels and responses to police incidents which would facilitate peak performance (Giessing et al., 2019; Nieuwenhuys & Oudejans, 2017). It is unclear whether chronically increased cortisol levels adequately prepare police officers to deal with physical threatening stressors (as suggested by Miller et al., 2007) or how much acute stress reactivity is needed for peak performance in critical incidents. In both cases, the long-term effects of these mechanisms on physical and mental health must not be neglected. Therefore, future research should relate longitudinal psychological and biological stress responses to occupationally relevant behaviors. In this context, the ability to maintain goal-directed attention should be considered in light of individual coping strategies, especially acceptance and reflection (e.g., Giessing et al., 2019; Landman et al., 2016). The identification of effective coping mechanisms producing health and performance benefits will eventually improve police training so that in the long run, officers are adequately prepared for the psychological demands encountered during police service.

Several limitations of the N-of-1 design and present study apply. Due to the correlational nature of the study and the concurrent assessment of all variables, the present data cannot establish a causal link from perceived stress to mood and biological stress markers. Since only few published reports on observational N-of-1 studies have used statistical analyses (rather than descriptive or visual inspection; McDonald et al., 2017), there is no clear consensus about which procedure to use in what circumstances. For the sake of clarity, comprehensibility, and transparency, we have adopted the user-friendly, but statistically robust dynamic regression modelling (Vieria et al., 2017; procedure described in McDonald et al., 2020). Similarly, there is an ongoing discussion about appropriate sample sizes (i.e., number of observations) in N-of-1 designs. The present study exceeds the recent recommendations of 50 data points in dynamic regression modelling (McDonald et al., 2020) with 84 daily observations spanning over three weeks. In the interpretation of the comparative sCort analyses, it must be acknowledged that average bedtime concentration might be overestimated due to the fixation of six bedtime samples to the detection threshold. Moreover, the intense data collection protocols in ecological momentary assessments might be burdensome and time-consuming for participants which may lead to decreasing compliance with ongoing sampling. While we observed a larger number of missing data points in the last week during a spontaneous weekend trip, the post-monitoring interview did not reveal irritation with the sampling protocol, so that the missing data during the trip can rather be explained by the non-availability of salivettes than by decreased compliance. Lastly, findings cannot be generalized – neither onto other police officers nor onto other weeks of police duty. Therefore, replication of the current findings is warranted. Various other intra- and interindividual factors have already been identified that influence stress responses, but have not been examined in the present study, e.g., sleep patterns, physical activity, work and training experience (Baldwin et al., 2019; Fekedulegn et al., 2018, Landman et al., 2016;

Planche et al., 2019). Since ecological momentary assessment protocols seems feasible in police service with careful planning, these influential variables can be tested in large-scale studies in a next step, utilizing multi-level analyses to estimate components of intra- and interindividual variance.

Importantly, ethical conduction of N-of-1 designs requires great care to ensure anonymity. Compliance with the Declaration of Helsinki is mandatory and as little person-specific information as possible may be collected and published. The police officer had the informed and voluntary choice to participate in the present study, and also made the final decision in publishing the results.

Conclusion

In conclusion, this is likely the first study to examine stress, mood, and salivary stress markers in a police officer during daily life using ecological momentary assessment. The results suggest police service to constitute a major stressor resulting in allostatic load. We observed clear signs of psychological and biological hyporesponsivity in moments of perceived stress and to police incidents. While physiological dysregulation of stress-responsive systems has already been linked to negative long-term health consequences (Adam et al., 2017; Violanti et al., 2018), the blunted stress responses to acute stressors might also impair officers' performance in critical situations that would require optimal functioning. Subsequently, the individual monitoring of stress functioning in training and on duty will advance the understanding of individual self-regulation processes in confrontation with potential police stressors. Further research should aim to estimate adaptive stress levels and to evaluate stress management strategies in order to promote police officers' health and performance.

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Table 1

Mean and standard deviation (in brackets) of daily measures based on original data (samples of police incidents not included)

	Awakening	30 min later	6 h later	Bedtime
Perceived stress	2.05	1.89	2.36	1.83
	(1.05)	(0.83)	(1.15)	(1.04)
Valence	6.53	6.83	6.61	6.42
	(0.75)	(0.24)	(0.98)	(0.91)
Energy	4.28	6.25	6.36	4.81
	(0.86)	(0.90)	(1.20)	(1.11)
Calmness	6.20	6.50	6.07	6.28
	(1.02)	(0.64)	(1.05)	(0.96)
sCort (nmol/L)	10.64	12.77	4.10	1.85
	(4.99)	(4.37)	(1.72)	(2.62)
sAA (U/ml)	56.22	56.57	166.13	77.28
	(19.44)	(26.75)	(51.23)	(37.41)

Note. sCort = salivary cortisol, sAA = salivary alpha-amylase. Ratings of stress, valence, energy and calmness range from 1 to 7.

Table 2

Overview of police incidents and participant's appraisal, emotion regulation, and responses

	Stressor	**Incident 1** Patrolling at soccer match, intermittent use of force, wearing full gear, high temperatures	**Incident 2** Car accident with rollover, full street closure, many emergency forces	**Incident 3** Routine car accident	**Incident 4** Car accident on the highway with findings of drugs, loud noise, many emergency forces	**Incident 5** Cooperative shoplifter	**Incident 6** Arrest after physical attack, use of force necessary
	Time	18:04	16:10	16:25	22:22	07:14	13:54
	Shift	09:30 – 19:30	11:00 – 23:00	06:00 – 18:00	20:00 – 06:00	06:00 – 14:00	06:00 – 14:00
	Delay	ongoing	45 min prior	25 min prior	10 min prior	ongoing	10 min prior
	Use of Force	defense and arrest skills	none	none	none	none	defense and arrest skills
Appraisal	Stressed	3	2	1	3	1	3
	Controllable	5	4	5	3	4	3
	Challenging	3	2	1	3	1	3
	Threatening	1	1	1	1	1	2
	Performance	5	4	5	3	5	4
Emotion Regulation	Reflection	5	2	5	5	1	5
	Reappraisal	1	1	1	1	1	1
	Rumination	2	1	1	3	1	1
	Social Sharing	1	1	1	3	1	3
	Expressive Suppression	1	1	1	1	1	1
	Distraction	1	1	1	1	1	1
	Acceptance	5	5	5	3	5	4
Responses (daytime mean)	Perceived stress	4 (3)	3 (3)	1 (2)	4 (2)	1 (3)	4 (3)
	Valence	5.5 (4.0)	6.0 (7.0)	6.5 (7.0)	6.0 (6.5)	6.5 (6.75)	6.5 (6.75)
	Energy	4.5 (5.0)	6.5 (5.5)	6.0 (7.0)	6.5 (5.5)	6.5 (4.75)	6.0 (4.75)
	Calmness	4.0 (5.0)	4.5 (5.0)	6.5 (6.5)	3.5 (6.0)	4.5 (5.25)	4.5 (5.25)
	sCort (in nmol/L)	1.99 (1.77)	4.39 (0.22)	4.58 (6.07)	2.13 (4.82)	4.69 (.41)	7.20 (.41)
	sAA (in U/ml)	152.60 (91.10)	97.20 (47.00)	116.60 (172.20)	112.60 (115.60)	27.40 (130.20)	31.00 (130.20)

Note. sCort = salivary cortisol, sAA = salivary alpha-amylase. Emotion regulation was assessed by Brans et al. (2013). Valence, energy and calmness was assessed by Wilhelm and Schoebi (2007).

Table 3

Statistical coefficients for the dynamic regression analyses on the salivary markers and mood

	F	R^2	*B*	*SE*	*95%CI*	*t*
sCort	**15.62*** **	.56				
Perceived stress			0.04	0.10	-0.16 – 0.23	0.39
Measurement Occasion			-0.30	0.12	-0.54 – -0.07	**-2.53***
sCort Lag 1			0.22	0.13	-0.02 – 0.47	1.79
sCort Lag 2			-0.21	0.13	-0.46 – 0.04	-1.65
sCort Lag 3			0.16	0.11	-0.07 – 0.38	1.38
sCort Lag 4			0.28	0.14	-0.01 – 0.55	1.88
sAA	**12.74*** **	.51				
Perceived stress			0.06	0.13	-0.20 – 0.32	0.45
Measurement Occasion			0.12	0.16	-0.19 – 0.43	0.75
sAA Lag 1			-0.10	0.16	-0.41 – 0.21	-0.65
sAA Lag 2			-0.09	0.14	-0.36 – 0.17	-0.68
sAA Lag 3			-0.12	0.10	-0.33 – 0.08	-1.20
sAA Lag 4			0.58	0.11	0.37 – 0.79	**5.37*** **
Valence	**11.08*** **	.20				
Perceived stress			-0.20	0.13	-0.45 – 0.05	-1.60
Valence Lag 1			0.37	0.12	0.14 – 0.61	**3.12** **
Energy	**4.45** **	.27				
Perceived stress			-0.14	0.13	-0.40 – 0.13	-1.04
Energy Lag 1			0.24	0.13	-0.01 – 0.49	1.90
Energy Lag 2			-0.23	0.12	-0.46 – 0.01	-1.87
Energy Lag 3			-0.02	0.12	-0.26 – 0.22	-0.17
Energy Lag 4			0.32	0.12	0.10 – 0.55	**2.77** **
Energy Lag 5			-0.25	0.12	-0.50 – 0.00	-1.97
Calmness	**74.94*** **	.47				
Perceived stress			-0.68	0.10	-0.88 – -0.48	**-6.66*** **

Note. sCort = salivary cortisol, sAA = salivary alpha-amylase. Bonferroni-correction was applied for mood scales, considering $p < .017$ as significant. *$p < .05$, **$p < .01$, ***$p < .001$

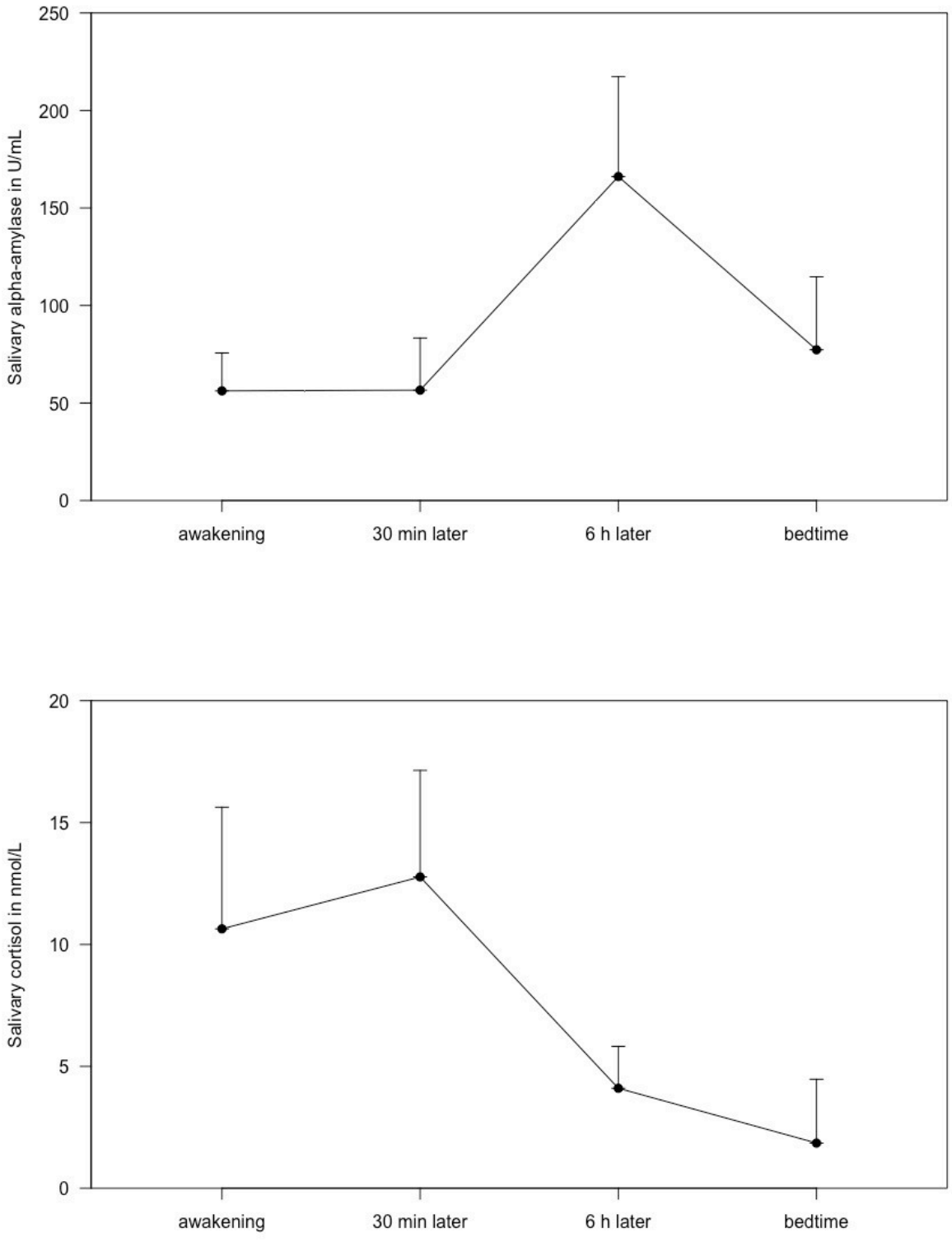


Figure 1. Salivary stress markers daily profiles throughout the 3-week period. Error bars represent standard deviation.

Supplementary Material

Supplement S1 Table

Comparison of the daily averages (mean, standard deviation in brackets) between on- and off-duty days

	On duty	Off duty	Mann-Whitney U *p*
Perceived stress	2.14	1.76	0.714
	(0.62)	(0.55)	
Valence	6.41	6.23	0.821
	(0.61)	(0.81)	
Energy	5.36	4.73	0.755
	(0.57)	(0.75)	
Calmness	5.83	6.05	0.831
	(0.57)	(0.49)	
sCort (nmol/L)	7.76	7.12	0.389
	(3.01)	(2.65)	
sAA (U/ml)	74.62	90.60	0.373
	(18.06)	(24.36)	

Note. sCort = salivary cortisol, sAA = salivary alpha-amylase. Ratings of stress, valence, energy and calmness range from 1 to 7.

Supplement S2 Table

Statistical coefficients of single linear regression models to assess periodicity

	F	R^2	*B*	*SE*	*t*
Measurement Occasion					
Perceived Stress	0.31	< .01	-0.03	0.11	-0.24
Valence	0.23	< .01	-0.03	0.11	-0.24
Energy	0.21	< .01	0.00	0.11	0.001
Calmness	1.52	0.02	0.12	0.10	1.16
sCort	56.96***	.44	-0.59	0.08	**-7.78*** **
sAA	10.79**	.12	0.30	0.10	**3.17** **
Shift work					
Perceived Stress	1.39	.02	0.16	0.18	0.86
Valence	0.90	.01	0.13	0.17	0.81
Energy	1.54	.02	0.18	0.17	1.09
Calmness	0.75	.01	-0.11	0.18	-0.60
sCort	1.07	.01	0.15	0.16	0.91
sAA	1.87	.02	-0.20	0.16	-1.28

Note. sCort = salivary cortisol, sAA = salivary alpha-amylase. ** $p < .01$. *** $p < .001$

Supplement S3 Table

Autocorrelations of perceived stress, mood, and salivary stress markers

Lag	Stress	Valence	Energy	Calmness	sCort	sAA
1	0.08	**0.39**	0.12	-0.02	0.10	-0.04
2	0.15	0.20	**-0.27**	0.08	**-0.54**	**-0.31**
3	0.07	0.14	0.01	-0.06	0.08	-0.13
4	-0.04	-0.02	**0.33**	-0.03	**0.62**	**0.64**
5	-0.08	0.10	-0.11	-0.01	-0.02	-0.09
6	0.00	0.01	**-0.33**	-0.16	**-0.51**	**-0.28**
7	0.03	0.04	0.06	0.09	0.04	-0.15
8	0.08	0.16	**0.29**	0.00	**0.47**	**0.51**

Note. sCort = salivary cortisol, sAA = salivary alpha-amylase. **Bold** = statistically significant with r > 0.21

Supplement S4 Table

Partial autocorrelations of perceived stress, mood, and salivary stress markers

Lag	Perceived Stress	Valence	Energy	Calmness	sCort	sAA
1	0.09	**0.40**	0.13	-0.02	0.09	-0.04
2	0.14	0.05	**-0.30**	0.08	**-0.56**	**-0.31**
3	0.04	0.04	0.10	-0.06	**0.30**	-0.17
4	-0.08	-0.11	**0.25**	-0.04	**0.37**	**0.59**
5	-0.10	0.17	**-0.22**	-0.01	-0.09	-0.20
6	0.01	-0.10	-0.16	-0.17	-0.14	-0.02
7	0.05	0.08	0.08	0.07	0.01	-0.06
8	0.08	0.12	0.11	0.03	0.05	0.12

Note. sCort = salivary cortisol, sAA = salivary alpha-amylase. **Bold** = statistically significant with r > 0.22

Supplement S5 Table

Autocorrelations of pre-whitened variables

Lag	Valence	Energy	sCort	sAA
1	-0.02	-0.04	0.03	0.11
2	0.03	0.07	0.09	0.01
3	0.11	0.03	0.05	-0.01
4	-0.13	-0.09	-0.11	-0.13
5	0.15	-0.05	-0.05	-0.04
6	-0.03	-0.05	0.01	-0.01
7	-0.01	0.09	0.00	-0.10
8	0.17	0.02	0.01	-0.08

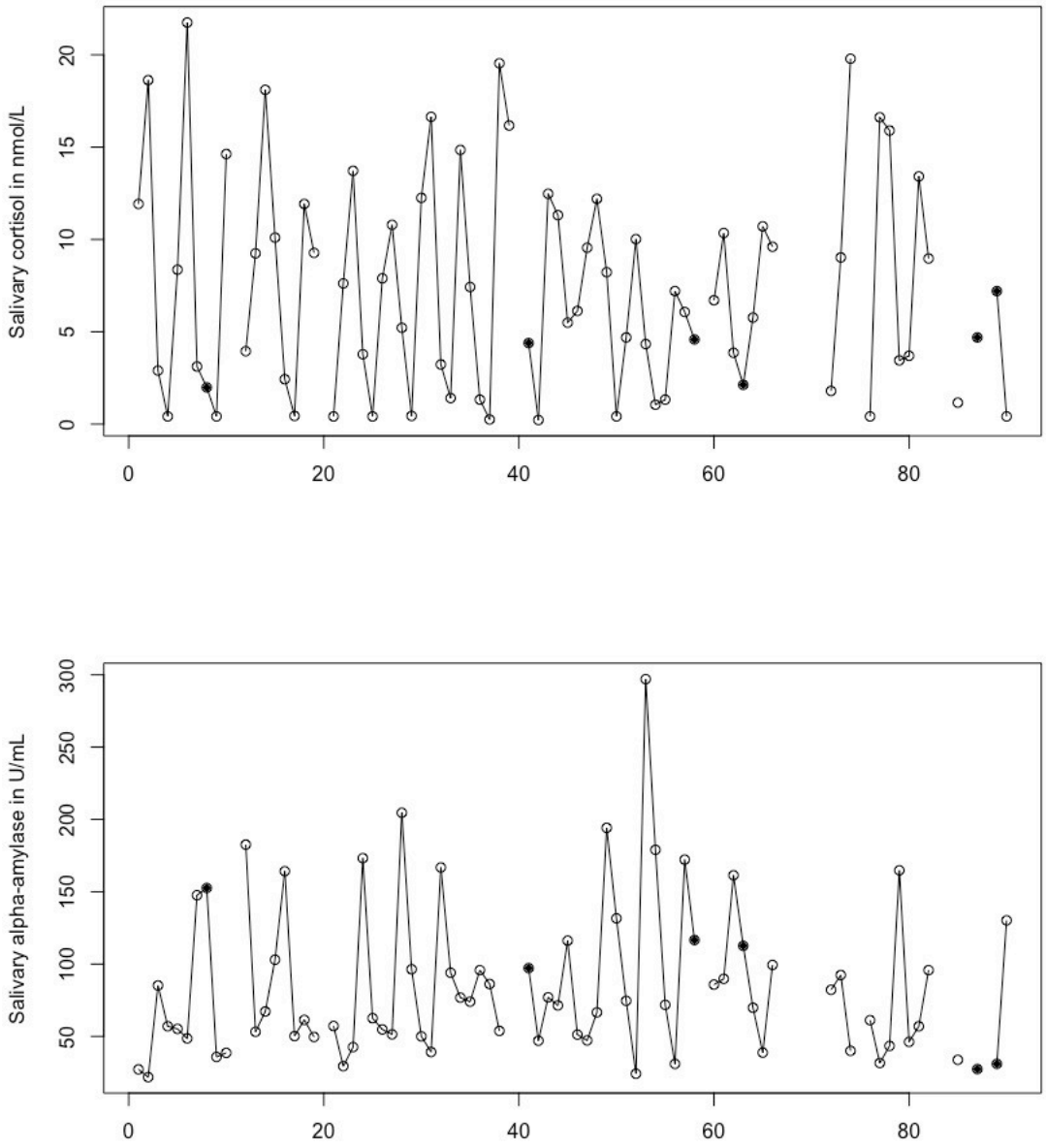
Note. sCort = salivary cortisol, sAA = salivary alpha-amylase.

Supplement S6 Table

Statistical coefficients of linear regression models to check effect of the past lags of the predictor perceived stress on outcome variables

	F	R^2	*B*	*SE*	*t*
sCort	0.49	.03			
Perceived Stress Lag 1			-0.10	0.11	-0.78
Perceived Stress Lag 2			0.04	0.13	0.33
Perceived Stress Lag 3			0.01	0.15	0.08
Perceived Stress Lag 4			-0.06	0.13	-0.44
sAA	1.52	.07			
Perceived Stress Lag 1			-0.08	0.13	-0.64
Perceived Stress Lag 2			0.15	0.13	1.15
Perceived Stress Lag 3			-0.20	0.15	-1.38
Perceived Stress Lag 4			0.10	0.14	0.70
Valence	1.50	.07			
Perceived Stress Lag 1			-0.01	0.18	-0.07
Perceived Stress Lag 2			-0.14	0.17	-0.85
Perceived Stress Lag 3			0.02	0.14	0.11
Perceived Stress Lag 4			0.14	0.16	0.88
Energy	0.51	.03			
Perceived Stress Lag 1			0.01	0.14	0.04
Perceived Stress Lag 2			-0.09	0.14	-0.68
Perceived Stress Lag 3			0.01	0.16	0.08
Perceived Stress Lag 4			0.08	0.14	0.54
Calmness	0.87	.04			
Perceived Stress Lag 1			-0.03	0.14	-0.24
Perceived Stress Lag 2			-0.16	0.16	-0.98
Perceived Stress Lag 3			0.02	0.13	0.12
Perceived Stress Lag 4			0.11	0.13	0.86

Note. sCort = salivary cortisol, sAA = salivary alpha-amylase.



Supplement Figure S1. Single values of salivary stress markers throughout the 3-week period (filled circles indicate samples of police incidents). In case of missing values, lines and circles are missing.

Appendix A3 – Manuscript 3

Giessing, L., Wadsley, C., Frenkel, M. O., & Nieuwenhuys, A. (2021). *Response Inhibition Under Physical and Emotional Stress*. Manuscript submitted for publication.

Response Inhibition under Emotional and Physical Stress

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We have no known conflict of interest to disclose.

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This study's design and hypotheses were preregistered; see https://osf.io/rndy2/?view_only=e3d4e5077d414412aa7ad9d219d92039. All data and the code behind this analysis have been made publicly available at the Open Science Framework and can be accessed at https://osf.io/wdtz7/?view_only=259621a3c73840eb89bb702c170cec2a.

Abstract

The ability to control action is crucial for goal-directed behavior in dynamic environments. However, action control may be compromised under emotional or physical stress. This preregistered study investigated how acute threat and vigorous exercise intensity may interact to influence 'response inhibition' – i.e., the ability to willfully stop preplanned action. Twenty-four participants (M_{age} = 23.19, SD_{age} = 3.11) performed an anticipatory response inhibition task under low threat versus high threat conditions whilst cycling for 2 x 30 minutes at light versus vigorous intensity on a stationary bicycle ergometer (i.e., 60% HRmax versus 86% HRmax). Using a switch mounted on the bicycle handlebar, participants responded to a rising indicator on a screen and were instructed to lift their finger off the switch as soon as the indicator reached a target line (i.e., Go trials; 70% of trials) or, on occasion, to inhibit their lifting response if the indicator automatically stopped rising before the target line (i.e., Stop trials; 30% of trials). Participants received mild electric shocks upon making task errors in the high threat but not low threat condition. Self-reported anxiety increased under high versus low threat conditions and perceived exertion increased under vigorous versus light exercise intensity. Contrary to our expectations, neither high threat nor vigorous exercise significantly altered Go- and Stop-trial performance. Adding to inconclusive literature to date, the current results suggest that response inhibition is robust against mild levels of task-relevant emotional stress and against effects of high physical stress.

Key words: threat of shock, physical exertion, exercise, acute stress, response inhibition

Introduction

Individuals in high stress domains such as police, medicine, military, and sports are expected to deliver peak performance in stressful environments. These domains are often simultaneously psychologically and physically challenging, requiring high levels of cognitive control to sustain attention, control movement and suppress inappropriate actions. The ability to willfully suppress or stop ongoing or preplanned actions – referred to as *response inhibition* – is considered a prerequisite for self-controlled, goal-directed behavior in dynamic environments (Verbruggen et al., 2019). For instance, a police officer who confronts an armed suspect after a physically effortful chase must withhold fire if the suspect surrenders. However, demanding situations that elicit stress and/or deplete resources are often associated with inhibitory control failure (e.g., van Peer et al., 2019). Although physical and emotional stressors are both known to activate biological systems and diminish attentional control (Eysenck et al., 2007; E. J. Hermans et al., 2014; Tenenbaum, 2001), intricate understanding about how they together influence response inhibition is currently lacking. As performance failure in high stress domains may have severe consequences, assessing the combined influence of varying stressors is an important step towards future interventions that aim to improve individuals' response inhibition in these environments.

In the laboratory, response inhibition has often been examined in either Go/NoGo tasks (Donders, 1868/1969) or stop-signal tasks (Lappin & Erikssen, 1966). In the former, participants respond to one type of stimulus (Go) as quickly as possible while withholding their responses to other stimuli (NoGo). In the latter, the Go signal is occasionally followed by a stop signal indicating that the initiated Go response is no longer required. In contrast to Go/NoGo tasks, stop-signal tasks provide a measure for the time it takes the participant to complete the inhibitory process after the appearance of the stop signal. Based on the independent horse race model (Logan & Cowan, 1984), the stop-signal reaction time (SSRT;

see e.g., Logan, 1994) can be calculated as a measure of the latency of response inhibition, with shorter SSRTs indicating superior inhibitory performance.

Maintaining inhibitory control is difficult in emotionally stressful situations. Neurobiological models of stress indicate that acute threat triggers a cascade of emotional (Lazarus & Folkman, 1984) and neuroendocrine stress responses (Dickerson & Kemeny, 2004). These responses have been shown to increase activity in the neurocognitive salience network, while suppressing the executive control network (E. J. Hermans et al., 2014). Together with threat-related increases in corticospinal excitability (Gökdemir et al., 2018; Hajcak et al., 2007; Oliveri et al., 2003; Schutter et al., 2008; van Loon et al., 2010), these neurophysiological changes promote increased attentional vigilance for potential threats and increased action readiness, facilitating fast stimulus-driven responses at the cost of goal-directed control (Bishop, 2008; E. J. Hermans et al., 2014). Although these stress responses are generally considered to be adaptive in "fight-or-flight" situations, they are accompanied by performance decrements in tasks requiring cognitive control (Eysenck et al., 2007; Nieuwenhuys & Oudejans, 2012; 2017).

In line with this account, response inhibition has been shown to be impaired under emotional stress. In Go/NoGo tasks, experimental manipulations of emotional stress typically result in faster Go responses and decreased response accuracy, specifically an increase in false alarms (De Houwer & Tibboel, 2010; Hashemi et al., 2019; Nieuwenhuys et al., 2012, 2015; D. Patton, 2014; Wilson et al., 2016; but cf. Gladwin et al., 2016; Robinson et al., 2013), suggesting an increased tendency to act. Additionally, studies using stop-signal tasks demonstrated an impaired ability to inhibit responses under emotional stress as indicated by increased SSRTs (Herbert & Sütterlin, 2011; Kalanthroff et al., 2013; Pessoa et al., 2012, Experiment 2; Rebetez et al., 2015; Roxburgh et al., 2019; van Peer et al., 2019; Verbruggen & Houwer, 2007). However, findings in these studies are less consistent (Pawliczek et al,

2013; Pessoa et al, 2012, Experiment 1; Robinson et al., 2013; Sagaspe et al., 2011; Senderecka, 2016; Weinbach et al., 2015), which might (in part) be explained by heterogeneous manipulations of emotional stress (van Peer et al., 2019). First, it has been shown that emotional stress of high intensity (i.e., shock conditioned stimuli, white noise bursts) impairs response inhibition, whereas emotional stress of low intensity (i.e., fearful face stimuli) improves response inhibition (Pessoa et al., 2012). This effect appears to critically depend on subjective threat perception, with individuals showing strong and weak subjective responses to the threat cue exhibiting performance decreasing and enhancing effects, respectively (Sebastian et al., 2020). Second, task-relevant, performance-contingent manipulations of stress, in which task errors are followed by a negative (aversive) consequence (e.g., threat of shock/noise; Hashemi et al., 2019; van Peer et al., 2019), may motivate good performance more readily than task-irrelevant stressors as compared to when the aversive stimulus is implemented irrespective of task performance (Wilson et al., 2016). With performance-contingent manipulations of emotional stress, participants may try harder to avoid the aversive stimulus, resulting in improved response times on Go trials but, at the same time, reducing inhibitory efficiency on Stop trials, as indicated by an increase in SSRT (van Peer et al., 2019).

Response inhibition may not only be compromised due to high levels of emotional stress, but also as a consequence of physical stress. Similar to emotional stress, physical stress above the ventilatory threshold or for extended durations can be considered an acute stressor that prompts a reallocation of neural resources from the frontal cortex to the reticular-activating system (Dietrich & Audiffren, 2011). This activation process facilitates performance in stimulus-driven reaction time tasks (Audiffren et al., 2008; Davranche & Audiffren, 2004; Davranche et al., 2005, 2006), while downregulation of the prefrontal cortex accounts for detrimental effects of physical stress on tasks that require executive control (e.g.,

Audiffren et al., 2009; Dietrich & Sparling, 2004; Eddy et al., 2015; Mahoney et al., 2007). In addition to neurophysiological changes, the parallel processing model (Rejeski, 1985) predicts a shift in attention allocation during high physical stress. That is, as physical stress increases, attention becomes increasingly focused on physiological, bodily sensations (i.e., internal association) at the expense of attention resources available for extraneous cues (Hutchinson & Tenenbaum, 2007). Empirical evidence for the effect of physical stress on response inhibition, however, is sparse. While moderate intensity exercise (i.e., at 60 – 70% of HR_{max} / 40% of maximum oxygen intake) has been found to improve inhibitory performance in Go/NoGo tasks (Chu et al., 2015; Joyce et al., 2009), decreased accuracy has been observed for exercise at higher intensity (at 75% of HR_{max} / 60% of maximum oxygen intake; Wohlwend et al., 2017; for a meta-analysis see Lambourne & Tomporowski, 2010).

Crucially, although individuals in high stress domains usually act under both emotional and physical stress, interactions between emotional and physical stress remain poorly understood. When combined, physical and emotional stress may produce a cancelling-out effect, with high physical stress limiting the capacity to process threat-related information (e.g., see findings regarding exercise-induced hypoalgesia; Koltyn et al., 2014; Vaegter & Jones, 2020) or, vice versa, with high emotional stress limiting the capacity to process sensations resulting from physical stress (e.g., Brunyé & Mahoney, 2019), with the direction of the effect depending on the relative intensity of either stressor (cf. Sebastian et al., 2020). Alternatively, it may be argued that combined emotional and physical stress result in additional negative effects on performance, as both stressors independently cause a shift from goal-directed towards stimulus-driven processing, thereby reducing capacity to deliberately control action (Nieuwenhuys & Oudejans, 2012, 2017). Directly speaking to these issues, Cantelon and colleagues (2019) recently showed that under low emotional stress, Go/NoGo task performance decreased (i.e., false alarms increased) with increasing physical stress but

that, under high emotional stress, false task performance improved (i.e., false alarms decreased) with increasing physical stress, suggesting that high emotional stress may have cancelled-out potential negative effects of physical stress on response inhibition. It should be noted, however, that they used a Go/NoGo rather than a stop-signal task to assess response inhibition, used a manipulation of emotional stress that was unrelated to the task (i.e., not performance-contingent), and used a manipulation of physical stress that was time-confounded (i.e., physical stress progressively increased over time). As such, whilst their study constitutes an important first step, it still remains an empirical question how (task-relevant) emotional stress and physical stress interact to influence response inhibition.

Building on the above, the current study investigated the main and interaction effects of emotional and physical stress on response inhibition in a full-panel experimental design. To assess response inhibition, our study used an anticipatory response inhibition (ARI) task paradigm (He et al., 2021) which, amongst the stop-signal task paradigms, provides the most reliable means of assessing the latency of individuals' inhibitory responses (Leunissen et al., 2017). Physical stress was manipulated within-subjects by having participants perform the ARI task whilst concurrently cycling on a bicycle ergometer at light versus vigorous intensity. During the task, emotional stress was manipulated within-subjects by delivering mild electric shocks (high threat) or no shock (low threat) upon making a task error (i.e., performance-contingent). Regarding the effect of emotional stress, we predicted improved performance on Go trials (i.e., improved Go response time accuracy) due to the heightened motivation to perform well (van Peer et al., 2019), but impaired inhibitory performance on Stop trials, as reflected in longer SSRTs under high compared to low threat (e.g., Herbert & Sütterlin, 2011; Kalanthroff et al., 2013; Pessoa et al., 2012, Experiment 2; Rebetez et al., 2015; Roxburgh et al., 2019; van Peer et al., 2019; Verbruggen & Houwer, 2007). Regarding the effect of physical stress, we predicted decreased vigilance (Dietrich & Audiffren, 2011; Tenenbaum,

2001), resulting in impaired Go response time accuracy and longer SSRTs in vigorous compared to light intensity (Wohlwend et al., 2017). Finally, as result of a potential cancelling-out effect between both stressors (see Cantelon et al., 2019), we anticipated an interaction between emotional and physical stress. In this respect, decreased subjective responses to emotional stress in the vigorous compared to light intensity condition (i.e., lower anxiety) would indicate that physical stress cancelled out effects of emotional stress. Vice versa, decreased responses to physical stress in the high compared to low threat condition (i.e., lower ratings of perceived exertion) would indicate that emotional stress cancelled out effects of physical stress. Behaviourally, in case of a cancelling-out effect, effects of physical stress may be more pronounced in the low emotional stress condition or, vice versa, effects of emotional stress may be more pronounced in the low physical stress condition.

Method

We report how we determined our sample size, all data exclusions (if any), all manipulations, and all measures in the study. The hypotheses, the experimental design, and the analysis plan for the current study were preregistered before data collection, see https://osf.io/rndy2/?view_only=e3d4e5077d414412aa7ad9d219d92039. All materials, raw data, and code for analysis are available online at https://osf.io/wdtz7/?view_only=259621a3c73840eb89bb702c170cec2a.

Participants

We aimed to include 24 participants based on an a priori power analysis. Using G*Power (Faul et al., 2007), the sample size was estimated with $\alpha = .05$ and 80% power for repeated measures ANOVA based on effect sizes from Cantelon and colleagues (2019), who found that false alarm rates increased during a 50 min bout of cycling at 84% HRmax under safe but not under threat conditions ($\eta^2_p = .22$). 28 students at the [name deleted to maintain

the integrity of the review process] were screened for participation in the study. Inclusion criteria were age between 18 and 50 years, right-handedness (measured with the abbreviated Edinburgh Handedness Inventory, EHI; Veale, 2014), readiness for physical activity (measured with the Physical Activity Readiness Questionnaire, PAR-Q; Thomas et al., 1992) and the absence of epileptic history, recurring headaches, implanted electronics or any other self-reported neurological or medical conditions (measured with a safety screening checklist). Four participants were excluded from the study for the following reasons: three participants did not meet the criteria (i.e., reporting autism spectrum disorder, supraventricular tachycardia, and ventricular septal defect, respectively) and one participant failed to complete the session. 24 participants (11 females, M_{age} = 23.19, SD_{age} = 3.11) remained and were included in the analysis. Participants' trait anxiety score (State-Trait Anxiety Inventory; Spielberger et al., 1983) was M = 44.36 (SD = 7.11) and their trait impulsiveness score (Barratt Impulsiveness Scale; J. H. Patton et al., 1995) was M = 64.21 (SD = 8.60), indicating that, in general, participants had no extraordinary tendency to respond with unusual levels of anxiety or impulsively across a range of situations and contexts.

All participants provided written informed consent. Study participation was reimbursed with a $40 gift voucher. The study was approved by the [name deleted to maintain the integrity of the review process] and performed in accordance with the declaration of Helsinki.

Design, Experimental Task and Conditions

The current study used a 2 x 2 design with emotional stress (low threat versus high threat) and physical stress (light versus vigorous intensity) as within-subject factors. Participants visited the laboratory individually for a single 2h session in which they completed two 30-minute bouts of continuous cycling at light or vigorous intensity. The order of both cycling bouts was counterbalanced across participants and a 20-minute break was

implemented in between to ensure adequate recovery. During the cycling bouts, participants performed an ARI task under low threat and high threat conditions as described below.

Anticipatory response inhibition task. Participants performed an unimanual version of the ARI task (see He et al., 2021). Participants were seated on the bicycle ergometer ~ 70cm in front of a large 22" monitor (Sony KDL22BX300; 60Hz refresh rate), which was positioned at eye level. Participants' right index finger rested on a switch mounted to the handlebar of the ergometer, resembling the shifting of gears (see Figure 1). A modified version of the open-source ARI paradigm (OSARI; He et al., 2021) was implemented in PsychoPy software (Version 3.1.2, Peirce et al., 2019). The visual display consisted of a bar (15 cm high) that vertically filled upwards in 1000 ms. A horizontal target line was positioned at 80% of the total bar height (i.e., 800 ms from onset; see Figure 1). Participants initiated trial onset by depressing the switch, upon which the bar started filling after a 500 ms delay. The primary goal of the task was to stop the filling of the bar at the target line as accurately as possible (Go trials; 70% of all trails) by releasing the switch. To reinforce Go task performance, the colour of the target line changed to green or red, depending on whether responses were within or outside 100 ms of the target. On a smaller number of trials, the bar automatically stopped filling prior to reaching the target (Stop trials; 30% of all trials). For Stop trials, participants were required to inhibit their Go response and keep the switch pressed down. The time at which the bar stopped filling (stop-signal delay, SSD) was initially set to 500 ms and was adjusted trial-by-trial based on a staircase procedure. SSD was either increased (less time to stop) or decreased (more time to stop) in steps of 33 ms (equivalent to ~ 2 frames) after a successful or unsuccessful Stop trial, respectively.

Participants completed a practice block of 30 trials (21 Go trials, 9 Stop trials) during warm-up to familiarize themselves with the ARI paradigm. In total, the experimental protocol consisted of 600 trials (420 Go trials, 180 Stop trials). Each exercise condition (i.e., light

versus vigorous intensity; see below for description) consisted of 10 blocks of 30 trials (5 blocks under high threat and 5 blocks under low threat; see below for description). Participants rested for 2-3 seconds between trials and 1 min between blocks, while continuing cycling. In addition to trial-by-trial feedback, summarized feedback was given at the end of each block to further encourage accurate responding.

Manipulation of emotional stress. Emotional stress was manipulated using a "threat-of-shock" protocol. Upon making task errors (i.e., failing to inhibit the response on a Stop trial or responding late on a Go trial), participants either received a mild electric shock (high threat) or no shock (low threat). Electric shocks (single-pulse, 200 μs, 400 V, 90mA) were delivered over the biceps brachii of the non-dominant arm using an electrical stimulator (Digitimer DS7A) that was connected to either end of the muscle belly using to Ag-Cl electrodes (Suretrace RTL 1800C-050). During warm-up on the bicycle ergometer (i.e., prior to starting the experimental session) participants were gradually accustomed to the shocks by the experimenter manually delivering a single 30mA, 60mA and 90mA shock (i.e., target intensity). Perceived intensity of the 90mA shock was then measured using a 10-point VAS scale (1 = none / no distress; 10 = agonizing / unbearable distress) and monitored throughout the experiment to ensure that participants would not exceed a VAS score of 4 ("uncomfortable"). During the experiment, emotional stress was manipulated on a block-by-block basis, with order randomized within participants and exercise conditions (i.e., light versus vigorous intensity). Participants were informed about threat versus no threat by means of a visual indicator on the screen (visible throughout the block).

Manipulation of physical stress. To manipulate physical stress, participants cycled on a bicycle ergometer (Velotron, SRAM Corporation, Chicago, Illinois) for 30 min at light and vigorous intensity, respectively. Based on the guidelines of the American College of Sports Medicine (Garber et al., 2011), exercise intensity was based on participant's individual

age-predicted maximal heart rate (HR_{max} = 207 – 0.7 x age). Participants cycled at 60% HR_{max} (+/- 7%) in the light intensity condition and at 86% HR_{max} (+/- 7%) in the vigorous intensity condition. Heart rate (HR) was monitored continuously during cycling using a chest belt (H10, Polar, Kempele, Finland). Prior to each condition, resistance on the bicycle ergometer was gradually increased from 50 W (in steps of 10 W) over 6-7 min until the target HR was achieved. As soon as participants reached their target HR, the response inhibition task started. Throughout the task, resistance on the bicycle ergometer was adjusted on a block-by-block basis when necessary, to ensure that participants' heart rate remained within the target zone. Each block was followed by a 1 min break in which participants continuously cycled and verbally reported perceived exertion, subjective anxiety and – for high threat blocks – perceived unpleasantness of the electric shocks. After completing the task in each condition, participants completed a 5 min cool-down protocol, cycling against low resistance (30-50 W). Between the conditions, participants rested for 20 min. Water was freely available throughout the session.

Dependent Variables

Perceived exertion. To verify subjective responses to our manipulation of exercise intensity, after each block, participants verbally rated their perceived exertion using the Borg Rating of Perceived Exertion (RPE) Scale (Borg, 1982), ranging from 6 (*no exertion at all*) to 20 (*maximal exertion*).

Self-reported anxiety. To verify subjective responses to our manipulation of threat, after each block, participants verbally reported how anxious they felt on a visual analogue scale ranging from 0 (*not at all anxious*) to 10 (*extremely anxious*; Anxiety Thermometer, Houtman & Bakker, 1989).

Behavioral Data. Response times (relative to trial start) were obtained directly from the task for each trial on which participants made a response (i.e., lifted their finger off the

switch). Trials with response times more than 400 ms from the target (0.6% of Go trials; L. Hermans et al., 2019) and with incorrect responses (26% of all trials) were considered errors and excluded from further analyses. Outliers (+/- 3 SD) were excluded before calculation of mean response times (0.5% of Go trials; cf. Wadsley et al., 2019). Following Coxon et al., (2007), '*lift times*' (LT; in ms) are reported by subtracting the target time (i.e., 800 ms) from the measured response time, thus reflecting the time difference between the response and the target (i.e., negative values indicate responses before the target, positive values indicate responses after the target).

Stop-signal reaction times (SSRT, in ms) were calculated for each participant and each condition, using the integration method (Verbruggen, et al., 2013). First, untrimmed response times (including response errors and outliers of response times; omissions were assigned the maximal response time of 1000 ms) were ordered by rank. Then the response time value corresponding to the achieved stop-response probability was chosen (e.g., 55^{th} percentile response time in case of unsuccessful stopping on 55% of Stop trials). Finally, SSRTs were calculated by subtracting the mean SSD from this response time value. Longer SSRTs indicate decreased response inhibition.

Statistical Analyses

Data were analyzed using linear mixed effects models via the lme4 package (version 1.1-27; Bates et al., 2015) in R (version 4.1.0; R Core Team, 2021). For all models, per-participant random adjustment to the fixed intercept ("random intercept") and per-participant random adjustments to the slopes ("random slopes"; including all possible random correlation terms among the random effects) were entered to use the maximal random effects structure (Barr et al., 2013). In cases of non-convergence, we simplified the random effects structure based on contributions of the variance components to the total variance, and adjusted control parameters in the lme4 package (see the R script at

https://osf.io/wdtz7/?view_only=259621a3c73840eb89bb702c170cec2a for more details on implementation, including random effects structures and issues of non-convergence).

All categorical predictors were coded using sum-to-zero contrasts. The following contrasts were used: Intensity: light = -1, vigorous = 1; Threat: LT = -1, HT = 1. To test the effects of the intensity manipulation, HR data and RPE were analyzed with the factors Threat (low, high) X Intensity (light, vigorous). To test the effects of threat manipulation, anxiety was analyzed with the factors Threat (low, high) X Intensity (light, vigorous) and ratings of unpleasantness were analyzed with the factor Intensity (light, vigorous). The behavioral measures of the ARI task (i.e., LTs and SSRTs) were analyzed in separate models with the factors Threat (low, high) X Intensity (light, vigorous). Unstandardized regression coefficients (i.e., slopes), are represented by *b* with standard errors in brackets. All *p*-values were determined with the Satterthwaite's approximation (cf. Luke, 2016), performed with the lmerTest package (version 3.1-3; Kuznetsova et al., 2020). To support statistically significant effects, the Bayes Factor in favour of the alternative hypothesis (BF) was calculated with Bayesian paired *t* tests using JASP software and its default options (Version 0.14.1; JASP Team, 2020). Effect sizes were interpreted as small (BF: 1 – 3), medium (BF: 3 – 10), or large (BF > 10; van Doorn et al., 2020). An annotated .jasp file, including distribution plots, data, and input options, is available at https://osf.io/wdtz7/?view_only=259621a3c73840eb89bb702c170cec2a).

In accordance with the preregistration, we have run various secondary analyses. The SSRT analyses reported below excluded one participant who did not adhere to the stop instructions (stop success below 40% in all conditions) as well as five participants by condition who had larger mean response times on stop trials than on Go trials (differences ranging from 0.25 to 3.71 ms; cf. Verbruggen et al., 2019, Recommendation 7). To verify the impact of these exclusion criteria, and the robustness of our main results, we reanalyzed our behavioral data

(LT and SSRT) without making these exclusions. To check for possible time trends, we have run additional analyses adding Block (1-10) and the interaction effect Block x Intensity as predictors in all models (except for SSRTs which are calculated across blocks). To check for the impact of dispositional impulsivity and anxiety, we have added impulsivity and anxiety scores as predictors in all models. The results of these analyses are reported in detail in the online supplemental material.

Results

Manipulation Checks

Descriptive statistics for participant's HR, rating of perceived exertion and self-reported anxiety can be found in Table 1.

HR and perceived exertion. The model for HR showed a strong main effect of exercise intensity (b = 22.20 (1.02), t(23.00) = 21.78, p < .001), with HR lower in the light compared to vigorous conditions ($BF_{10} = 1.33 \times 10^{14}$), and a significant main effect of threat (b = 0.68 (0.19), t(23.09) = 3.69, p = .001), with HR larger in the high threat compared to low threat condition (BF_{10} = 56.12). There was no threat × intensity interaction (b = 0.08 (0.16), t(406.25) = 0.49, p = .627). The model for RPE scores indicated a strong and significant main effect of exercise intensity (b = 2.36 (0.19), t(23.00) = 12.57, p < .001), with RPE score lower in the light compared to vigorous intensity condition ($BF_{10} = 1.96 \times 10^{9}$). There was no fixed effect of threat (b = 0.06 (0.05), t(115.88) = 1.16, p = .249), and no threat × intensity interaction, b = -0.07 (0.05), t(25.21) = -1.35, p = .190).

Self-reported anxiety. The model for self-reported anxiety showed no significant main effect of exercise intensity (b = -0.24 (0.12), t(23.00) = 1.95, p = .064), a significant main effect of threat (b = 0.64 (0.12), t(23.01) = 5.45, p < .001), and a significant interaction between exercise intensity and threat, b = -0.10 (0.04), t(22.89) = -2.37, p = .027. Post-hoc Bayesian t-tests revealed that across both exercise intensity conditions, anxiety was higher

under high-threat as compared to low-threat conditions, with $BF_{10} = 1.23 \times 10^4$ and $BF_{10} = 66.46$ for light and vigorous exercise intensity, respectively. In addition, under low threat, anxiety was lower at light as compared to vigorous exercise intensity (BF = 3.28). There was no difference in anxiety between light and vigorous exercise intensity under high threat (BF = 0.36).

Behavioral Data

Descriptive statistics for the behavioral data can be found in Table 2. Figure 2 shows condition averages and individual participant means for LT and SSRT.

Lift times. The model for lift times showed no significant main effect of exercise intensity (b = -2.11 (1.12), t(22.94) = -1.88, p = .073), no significant main effect of threat (b = -0.04 (0.89), t(22.86) = 0.05, p = .961), and no significant interaction, b = -0.01 (0.61), t(23.02) = -0.02, p = .985 (see Figure 2A).

Stop-signal reaction times. The model for SSRTs also showed no significant main effect of exercise intensity (b = 1.05 (1.57), t(21.80) = 0.67, p = .509), no significant main effect of threat (b = -0.72 (1.40), t(35.67) = -0.52, p = .609), and no significant interaction, b = -0.14 (1.33), t(41.66) = -0.10, p = .917 (see Figure 2B).

Discussion

The current study investigated the effects of emotional and physical stress on response inhibition in an anticipatory response inhibition (ARI) task. We predicted that emotional stress (high threat versus low threat) would result in more accurate Go response times and decreased response inhibition, that physical stress (vigorous versus light exercise intensity) would result in less accurate Go response times and decreased response inhibition, and that, combined, one of the stressors would cancel-out effects of the other stressor, with the direction of the effect depending on the relative intensity of either stressor. Despite successful

manipulation of threat and exercise intensity, our results do not show any main or interaction effects of emotional and physical stress on Go response times or response inhibition.

Effects of Emotional Stress on Response Inhibition

Contrary to our hypothesis, high threat neither resulted in more accurate response times nor longer SSRTs. Emotional stress activates the salience network (Hermans et al., 2014), triggering neurophysiological and psychological changes that promote fast stimulus-driven responding at the cost of goal-directed control (Nieuwenhuys & Oudejans, 2012; 2017). In line with this account, previous work has shown that while Go response times may improve under high emotional stress, inhibitory performance is often decreased (De Houwer & Tibboel, 2010; Hashemi et al., 2019; Nieuwenhuys et al., 2012, 2015; D. Patton, 2014; van Peer et al., 2019; Wilson et al., 2016). As noted by van Peer et al. (2019), however, emotional stress may either enhance (Senderecka, 2016; Robinson et al., 2013; Weinbach et al., 2015) or impair response inhibition (Herbert & Sütterlin, 2011; Kalanthroff et al., 2013; Pessoa et al., 2012, Experiment 2; Rebetez et al., 2015; Roxburgh et al., 2019; van Peer et al., 2019; Verbruggen & Houwer, 2007), depending on the intensity of the stressor or whether the stressor is task-relevant (performance-contingent) or task-irrelevant (independent of performance; for a more in-depth discussion of possible moderators also see Roos, Knight, Beauchamp, Giuliano et al., 2017; Shields et al., 2016). Indeed, a recent study by Sebastian et al. (2020) showed that while highly anxious participants showed impaired response inhibition in relation to high threat stimuli, less anxious participants showed improved performance. Although self-reported anxiety was higher under high threat than under low threat in the current study, values were rather low compared to previous studies that used comparable task-relevant manipulations of emotional stress (e.g., Nieuwenhuys et al., 2012, 2015; van Peer et al., 2019). Potentially, relatively low levels of anxiety allowed participants to successfully (re)direct available resources to task execution (i.e., invest extra mental effort) as they

attempted to prevent negative consequences of error-making (i.e., shock) by upholding their inhibitory and Go task performance (cf. Eysenck et al., 2007; Nieuwenhuys & Oudejans, 2012, 2017). Regardless of the mechanism, findings of the current study suggest that response inhibition, as measured in a unimanual anticipatory response inhibition task, is robust against mild levels of task-relevant emotional stress.

Effects of Physical Stress on Response Inhibition

Both HR data and subjective reports of perceived exertion confirmed that the intensity manipulation of physical stress was effective. However, in contrast to our expectations based on the neurocognitive model (Dietrich & Audiffren, 2011) and parallel processing model (Rejeski, 1985; Tenenbaum, 2001), participants did not demonstrate less accurate Go response times or larger SSRTs under physical stress. Although meta-analytic findings suggest that cognitive task performance is impaired during high-intensity exercise (Chang et al., 2012; Lambourne & Tomporowski), a potential explanation for our seemingly unexpected findings may be sought in the distinction between cognitive inhibition and response inhibition (cf. Shields et al., 2016). While response inhibition refers to the suppression or termination of prepotent responses, cognitive inhibition – also known as interference control – refers to selectively attending to relevant information whilst ignoring irrelevant information. So far, most research on the effects of physical stress have focused on cognitive inhibition (e.g., Eriksen's Flanker Task, Stroop Task; cf. Ludyga et al., 2016;), while findings on response inhibition (i.e., in stop-signal tasks) are sparse (Chu et al., 2015; Joyce et al., 2009) and – in some cases – investigated effects on response inhibition *after*, not during the exercise. Importantly, cognitive and response inhibition rely on distinct neural processes and systems (Aron, 2007; Friedman & Miyake, 2004) and might, therefore, be differentially affected by physical stress (for a similar argument relating to emotional stress see Roos, Knight, Beauchamp, Giuliano et al., 2017; Shields et al., 2016). Findings of the current study suggest

that response inhibition, as measured in a unimanual anticipatory response inhibition task, is robust against high physical stress (in this case: concurrent vigorous exercise).

Combined Effects of Emotional and Physical Stress

In contrast to the results of Cantelon et al. (2019), who observed effects of physical stress to be restricted to the low emotional stress condition, our results provide no evidence for a cancelling out effect between emotional and physical stress. Similarly, no evidence was observed for the assumption that a combination of high emotional and physical stress would lead to additionally negative effects on task performance (Nieuwenhuys & Oudejans, 2017). Of note, in our study, vigorous exercise intensity elevated anxiety perceptions under low-threat conditions (see Table 1), suggesting that – to some extent –vigorous exercise may trigger subjective responses (e.g., perceived exertion) that can function as emotional stressors in and of themselves (e.g., Hall et al., 2002; Raglin & Wilson, 1996). Arguably, the anxiety-inducing effect of vigorous exercise reduced the relative difference between our emotional stress conditions and, hence, may have concealed potential main and interaction effects on task performance. Moving beyond the level of subjective perception, future studies are required to examine the conditions under which emotional and physical stress may interact to influence task performance.

Strengths, Limitations, and Future Directions

Adding to the sparse or at best inconclusive literature on the impact of emotional and physical stress on response inhibition, the current results suggest that inhibitory control is relatively robust against emotional and physical stress. The current study expanded the existing literature by employing a rigorous full-panel experimental design and the ARI task to obtain reliable estimates of SSRTs as a pure measure of the stop process (Leunissen et al., 2017). However, we also note some limitations. As our sample consisted of healthy, right-handed adolescents with a rather high educational status, conclusions on other populations,

especially in high-stress domains such as police, medicine, military, and sports, need to be treated with caution. There is preliminary evidence that individuals in high-stress domains may show attenuated stress responses to acute stressors (Frenkel et al., 2018; Giessing et al., 2019, 2020) and potentially, have better physical fitness than the general population. As individual differences in stress reactivity seem to play a role in the ability to maintain response inhibition under stress (Krypotos et al., 2011; Roos, Knight, Beauchamp, Berkman et al., 2017; Shields et al., 2015), future research should include measurements of biological stress markers in addition to self-reports, especially in high-stress populations. The participants in the current study were ready to engage in physical exercise, but were not highly trained and had no specific cycling experience. Although (treadmill) running is assumed to require considerably more balance and body coordination than cycling (Lambourne & Tomporowski, 2010; Pesce, 2009), behavioral data in the current study hints at a potential interference of the cycling task with the task performance. Although we have no direct comparison of task performance without cycling in the current study, mean LTs on Go trials are longer and standard deviations are larger compared to other studies using unimanual ARI tasks (e.g., mean LT of ~10 ms in Coxon et al., 2007). Together with the anxiety-inducing effect of vigorous exercise, the reduced overall performance and introduced variability in task performance may have occluded potential effects of exercise intensity and threat. Therefore, recruiting a sample for whom the cycling task is more familiar might reduce interference and yield different results.

Conclusion

The ability to willfully inhibit ongoing or preplanned actions is crucial for goal-directed behavior and peak performance in high-stress domains which are simultaneously emotionally and physically challenging. Although a great body of literature has shown decrements in cognitive and motor performance under these circumstances (Dietrich & Audiffren, 2011;

Nieuwenhuys & Oudejans, 2012, 2017), the current findings suggest that – under experimental conditions – response inhibition may be relatively robust against effects of emotional and physical stress. In light of rather low anxiety scores, the investment of extra mental effort might serve to successfully (re)direct available to resources to task execution and mitigate negative effects of stress on response inhibition. Given that action control is crucial in high-stress professions, future research should bear in mind the practical implications of response inhibition under physical and emotional stress to inform interventions that aim to improve performance in high-stress situations.

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Table 1

Means and Standard Deviations of the Manipulation Checks

	Light Intensity		Vigorous Intensity	
	Low Threat	High Threat	Low Threat	High Threat
Heart Rate (bpm)	122.86 (11.51)	123.82 (11.729	166.99 (9.40)	168.50 (9.70)
Perceived Exertion (6-20)	10.12 (4.94)	10.43 (2.20)	15.00 (1.94)	14.98 (1.82)
Anxiety (0-10)	1.67 (1.50)	3.12 (1.77)	2.36 (2.05)	3.43 (2.16)

Table 2

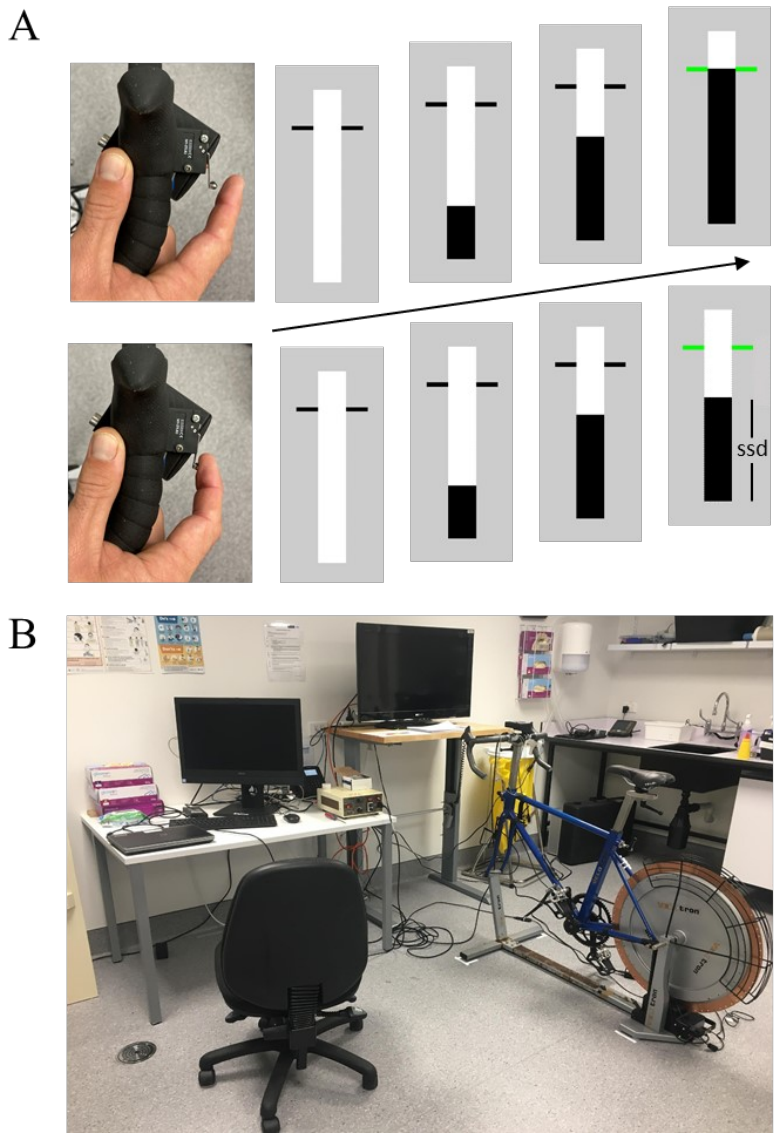
Means and Standard Deviations of the Behavioral Results in the Stop-Signal Task

	Light Intensity		Vigorous Intensity	
	Low Threat	High Threat	Low Threat	High Threat
Go Trials				
Trial success	.85 (.10)	.80 (.13)	.85 (.10)	.83 (.10)
Omission error	.01 (.02)	.01 (.02)	.01 (.03)	.01 (.02)
Response time (ms)	834 (35)	833 (37)	830 (37)	830 (38)
Lift time (ms)	34 (35)	33 (37)	30 (37)	30 (38)
Stop Trials				
Stop success	.52 (.02)	.52 (.02)	.52 (.03)	.52 (.03)
Stop fail response time (ms)	823 (53)	820 (91)	807 (106)	814 (81)
SSD (ms)	550 (41)	552 (43)	545 (40)	546 (49)
SSRT (ms)	293 (13)	292 (17)	295 (17)	293 (24)

Note. Trial success = proportion of Go trials on which the response was within 100 ms of the target line; SSD = stop-signal delay; SSRT = stop-signal response time estimated using the integration method.

Figure 1

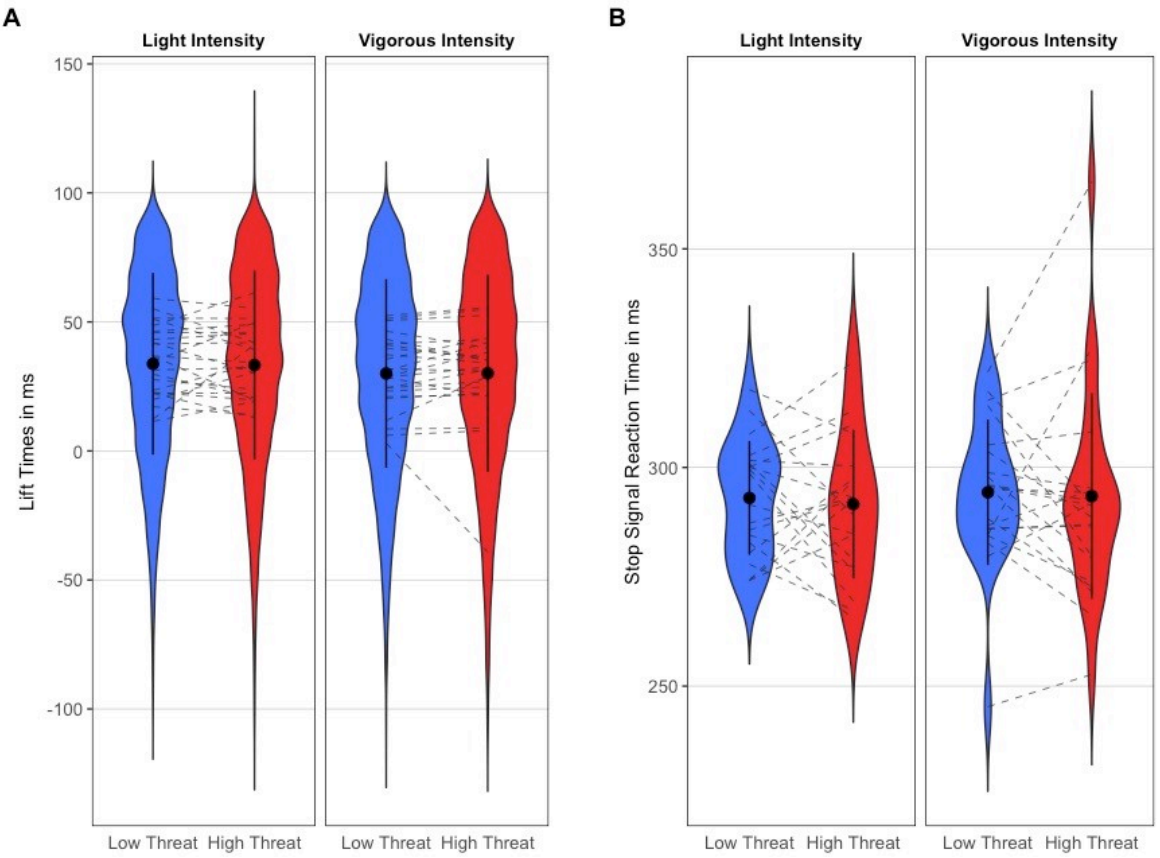
Anticipatory Response Inhibition Task (A) and Experimental Setup (B).



Note. Panel A: Anticipatory response inhibition task. Trials began when the switch was depressed. After a brief delay (500 ms), the bar (black) began to rise. The objective during Go trials (80% of all trials) was to release the switch when the bar reached the target line (horizontal black line, i.e., after 800 ms). Go trials were considered successful if the indicator was stopped (switch released) within 100 ms of the target line. For Stop trials (30%), the bar automatically ceased filling prior to reaching the target (Stop signal), and participants were required to keep the switch pressed down. The time at which the bar stopped filling (stop-signal delay, SSD) was initially set to 500 ms and was adjusted upward or downward in steps of 33 ms on a trial-by-trial basis, dependent on the success of the previous Stop trial. Panel B: Experimental set-up. Participants were seated on the bicycle ergometer (Velotron, SRAM Corporation, Chicago, Illinois) ~70cm in front of a 22” monitor with a 60 Hz refresh rate, positioned at eye level (SONY KDL22BX300). To deliver electric shocks in the high threat condition, two electrodes (Suretrace RTL 1800C-050) were attached on the biceps brachii of the non-dominant arm and connected to a custom electrical stimulator (Digitimer DS7A).

Figure 2

Violin Plots of Go Lift Times (A) and Stop-Signal Reaction Times (B) by Condition



Note. The dot shows the mean value in each condition, and the error bar represents standard deviation. The width depicts the density of the distribution. The dashed lines represent condition means of each participant.

Supplementary Material

Additional Results Time Trends

To check for possible time trends, we have run additional analyses adding Block (1-10) and the interaction effect Block x Intensity as predictors in all models (except for SSRTs which are calculated across blocks). See Table S1 for the inferential statistics of the possible time trends.

HR and perceived exertion showed a significant main effect of block, indicating an increase of HR and greater exertion with each block. Importantly, controlling for the time trend did not change the significance of the main effect of intensity (and threat for the HR model). When controlling for the time trend, perceived exertion also showed a significant main effect of threat. Anxiety and lift times (LT) showed no significant time trends. There was no interaction effect for Block x Intensity.

Additional Results Personality Traits

To check for the impact of dispositional impulsivity and anxiety, we have added impulsivity and anxiety scores as predictors in all models. See Table S2 for the inferential statistics.

Dispositional impulsivity and anxiety did not significantly influence perceived exertion, anxiety, LTs and SSRTs. HR showed a significant effect of impulsivity, with lower impulsivity predicting greater HR.

Robustness Checks

The analyses reported in the main text excluded one participant that did not adhere to stop instructions for the SSRT analyses (see main text, Statistical Analyses). To verify the impact of our exclusion criteria, and the robustness of the results that are reported in the main text, we re-analyzed our SSRT data without making these exclusions. For completeness, these results are reported in detail below.

Including the one participant did not adhere to stop instructions did not cause the SSRT results to change: All main effects and the interaction effect remained not significant (Intensity: b = 1.35 (1.46), t(43.34) = 0.92, p = .362; Threat: b = -1.33 (1.48), t(41.79) = -0.90, p = .372; Intensity x Threat: b = -0.71 (1.35), t(68.99) = -0.53, p = .599).

Based on the argument that non-adherence was specific to stop instructions, in the original analyses the non-adhering participant was only excluded from the SSRT analyses and not from the LT analyses. However, our robustness analysis showed that *excluding* this participant from the LT analyses did not change the results. All main effects and the interaction effect remained not significant (Intensity: b = 1.45 (0.93), t(22.15) = -1.55, p = .135; Threat: b = 0.58 (0.73), t(22.21) = 0.80, p = .434; Intensity x Threat: b = 0.32 (0.53), t(22.98) = 0.61, p = .549).

Taken together, these findings confirm that the participant's non-adherence to task instructions did not alter the results of the main analyses.

Table S1

Results of the Time Trend Analyses

	Block		Intensity		Threat		Block x Intensity		Intensity x Threat	
	b	*t*	*b*	*t*	*b*	*t*	*b*	*t*	*b*	*t*
Heart Rate	0.34 (0.10)	3.35**	22.59 (0.97)	23.24***	0.80 (0.17)	4.60***	-0.07 (0.12)	-0.62	-0.02 (0.15)	-0.16
Perceived Exertion	0.23 (0.03)	6.70***	2.22 (0.20)	10.88***	0.11 (0.04)	2.76*	0.02 (0.03)	0.82	-0.05 (0.05)	-1.12
Anxiety	-0.02 (0.03)	-0.73	0.28 (0.11)	2.66*	0.63 (0.05)	12.62***	-0.01 (0.02)	-0.40	-0.09 (0.05)	-1.77
Lift Times	-0.25 (0.30)	-0.83	-3.73 (2.06)	-1.82	0.05 (0.88)	0.06	0.30 (0.30)	0.98	-0.03 (0.61)	-0.05

Note. * $p > .05$, ** $p > .01$, *** $p > .001$

Table S2

Results of the Personality Trait Analyses

	Impulsivity		Trait Anxiety		Intensity		Threat		Intensity x Threat	
	b	*t*	*b*	*t*	*b*	*t*	*b*	*t*	*b*	*t*
Heart Rate	-0.52 (0.18)	-2.83*	-0.14 (0.22)	-0.63	22.20 (1.02)	21.79***	0.68 (0.19)	3.64**	0.08 (0.17)	0.45
Perceived Exertion	-0.02 (0.04)	-0.52	0.04 (0.04)	0.93	2.36 (0.19)	12.57***	0.06 (0.05)	1.17	-0.07 (0.05)	-1.41
Anxiety	0.03 (0.03)	1.05	0.05 (0.04)	1.24	0.24 (0.12)	1.95	0.64 (0.12)	5.45***	-0.10 (0.04)	-2.37*
Lift Times	-0.27 (0.28)	-0.98	0.59 (0.33)	1.79	-2.12 (1.12)	-1.89	0.05 (0.89)	0.06	-0.02 (0.61)	-0.03
SSRT	0.07 (0.32)	0.22	-0.33 (0.37)	-0.88	1.08 (1.58)	0.68	-0.76 (1.39)	-0.55	-0.16 (1.33)	-0.12

Note. SSRT = stop signal response time estimated using the integration method. * $p > .05$, ** $p > .01$, *** $p > .001$

Appendix A4 – Manuscript 4

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Chapter 6
The Potential of Virtual Reality for Police Training Under Stress: A SWOT Analysis

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ABSTRACT

To prepare for critical incidents on duty, police officers need to acquire the skills and tactics in realistic environments so that they transfer to high-stress circumstances. To bridge the gap between empirical research and applied practice, the present chapter informs about training concepts within the ecological dynamics framework that effectively promotes performance under stress. Specifically, scenario-based police training is critically discussed by identifying research gaps and challenges in the current practice. Virtual reality (VR) is introduced as a promising tool to overcome these challenges in police training and research. The aim of the present chapter is to inform, update, and improve researchers', police trainers', and curriculum developers' knowledge of VR as a tool to address the need for representative stress training while acknowledging its strengths, weaknesses, opportunities, and threats.

INTRODUCTION

On duty, police officers are entrusted with the task to ensure the personal safety of citizens, in some cases necessitating the use of (potentially lethal) force. As a result, the most far-reaching decisions and actions by police officers usually occur in highly stressful, unpredictable, ambiguous, and rapidly unfolding situations. Although the majority of calls for services involve non-threatening duties, in those rare situations of high threat, officers need to perform in complex and unforgiving environments, which require optimal task performance. Performance failure in these situations may have tremendous – potentially lethal – consequences for the officers themselves, colleagues, suspects, or innocent bystanders. Therefore, the essential challenge for police academies is to teach officers skills and tactics in such a way that they transfer even to the high-stress circumstances on police duty.

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Critically, there is little evidence that officers are immune to the body's automatic responses to threat and stress (Anderson et al., 2002; Baldwin et al., 2019; Giessing et al., 2020). When individual coping resources are judged as insufficient to meet the environmental demands (Lazarus and Folkman, 1984), stress arises. Stress leads to a variety of consequences for the individual, including emotional responses (e.g., anxiety) and physiological changes (e.g., increased heart rate, cortisol secretion; McEwen and Stellar, 1993). These stress responses influence cognition and behavior by shifting attention from goal-directed control to stimulus-driven control (Eysenck et al.,2007; Hermans et al., 2014) – sometimes resulting in impaired police performance (Arble et al., 2019; Giessing et al., 2019; Hope, 2016; Nieuwenhuys and Oudejans, 2010; Nieuwenhuys et al., 2012, 2017; Renden et al., 2013, 2017; Taverniers and De Boeck, 2014, for an overview see Nieuwenhuys and Oudejans, 2017). However, while performance might be challenging, most officers manage to solve even stressful situations professionally and adequately. Apparently, individuals are able and also highly motivated to counteract the debilitative effects of stress: they are predicted to spend extra mental effort in an attempt to reduce stress responses, enforce goal-directed processing of information, and inhibit stimulus-driven impulses (Eysenck et al., 2007; Nieuwenhuys and Oudejans, 2017). Therefore, police training should provide police officers with the opportunity to experience psychophysiological stress responses and their impact on behavior in order to develop and try out effective coping strategies.

Given the inherent complexity and stress of police work, it has been recently highlighted that police training should develop officers to be independent, creative problem solvers despite elevated stress levels (Blumberg et al., 2019; Staller and Zaiser, 2015). To achieve this, police academies should primarily follow the training principle of "train as you fight", which aims to replicate the performance context as closely as possible to maximize learning outcomes (e.g., Low et al., 2020). The decisive difference between real police operations and training situations is the extent of threat and stress. Therefore, police training should create representative environments that incorporate situational constraints from real-life contexts with the aim to put trainees under stress (Anderson et al., 2019; Di Nota and Huhta, 2019).

Although training under stress might not be able to perfectly replicate real-life stress situations, it has been shown to enhance performance delivery in various high-stress domains (Gröpel and Mesagno, 2017; Kent et al., 2018; Low et al., 2020), including law enforcement (Oudejans, 2008; Nieuwenhuys and Oudejans, 2010, 2011). However, various open questions and challenges remain in the implementation of the principles of training under stress into police training. New technologies such as Virtual Reality (VR) offer the potential to address these challenges. Therefore, the present chapter conducts an analysis of the strengths, weaknesses, opportunities, and threats (SWOT) associated with the use of VR in scenario-based stress training in police settings. SWOT analyses are widely utilized as a strategic planning methodology to meet goals and improve operations in developmental processes (Pickton and Wright, 1998; Tao and Shi, 2016). As such, the aim of the present chapter is to inform, update, and improve researchers', police trainers', and curriculum developers' knowledge of VR as a tool to address the need for representative stress training while acknowledging its strengths, weaknesses, opportunities and threats.

"TRAIN AS YOU FIGHT": SCENARIO-BASED TRAINING UNDER STRESS

In police training, scenario-based training is considered the gold-standard for complex motor learning (Di Nota and Huhta, 2019). By nature, it is fully immersive: In real or artificially constructed environments, props, sounds, and lighting are used to expose police officers to realistic and occupationally relevant

stressors (i.e., emotional or situational constraints). Professional actors or experienced police instructors role-play various types of critical incidents ranging from vehicle controls to domestic disputes to shooting incidents. In the ideal case, the role plays follow a very detailed script that specifies the context and course of the role play, the logistical requirements, and the learning objectives and evaluation standards. In post-scenario debriefings, trainees articulate their decision-making processes and police trainers provide constructive and immediate feedback on the trainee's performance. Through discussions and mental simulations, trainees can identify their weaknesses and learn how to adapt their behavior and improve future performance (Anderson et al., 2019; Di Nota and Huhta, 2019; Jenkins et al., in press). As such, a practical integration of verbal, physical, cognitive, and psychological skills under realistic circumstances is requested from trainees. Therefore, scenario-based training offers a great opportunity (although not the only one, see Staller and Körner, 2019) to apply the ecological dynamics framework in police training.

According to the ecological dynamics framework (Araújo and Davids, 2011; Körner and Staller, 2018), skill learning refers to the process of adapting and attuning to the environment and its constraints. The situational constraints and the action capabilities of the acting person will determine the way of solving the task. In training, the police trainer acts as a designer of the learning environment, who matches the situational constraints of the environment with the trainee's individual capabilities to create the best possible learning experience. Following the principle of representativeness (Araújo et al., 2007), scenario content should be based on situations and events trainees will typically face in their day-to-day duties. While scenario-based training may include preparation for worst-case events, in terms of representativeness, simulated scenarios and their situational characteristics should be sampled from real-life critical incidents, achieving similar occurrence probabilities in the learning and performance environment (Brunswik, 1956; Araújo et al., 2007; Pinder et al., 2011). Thus, rare conditions in police service (e.g., optimal light and enough time for stable two-handed static stance shooting situations) should seldomly occur in police training. At the same time, an overrepresentation of worst-case events should be avoided as the probability of such rare events might be overweighted – at the expense of learning how to deal with the most common police duties (Anderson et al., 2019).

So far, physical, technical, and tactical performance have been emphasized in police training, while effects of stress have typically been neglected (Blumberg et al., 2019; Hope, 2016). In terms of representativeness in the ecological dynamics framework model, it is important to simulate the physical, perceptual-cognitive, and affective representation of critical police incidents (Headrick et al., 2015; Körner and Staller, 2018). Physical representations in the training environments consider physical features found in real encounters, e.g., weapons, the intensity of attacks. Perceptual-cognitive elements influence individual decision-making and the execution of actions. Affective elements affect the psychological or emotional state of the trainee (Körner and Staller, 2018; for similar dimensions of training representativeness see Wollert and Quail, 2018). Psychophysiological changes in response to stress (McEwen and Stellar, 1993) can be considered as affective representations, as they directly influence the psychological experience and in turn mental processes (Nieuwenhuys and Oudejans, 2012, 2017). Experiencing the debilitative effects of stress on their attention and behavior allows police officers to attune and adapt to the environment by discovering and trying out functional problem solutions, including effective coping strategies (Headrick et al., 2015; Körner and Staller, 2018).

The Potential of Virtual Reality for Police Training Under Stress

Principles of Training Under Stress

Trainings that focus on the manipulation of affective or emotional constraints (Headrick et al., 2015) are known as training under stress or pressure training and their application is widely spread in domains such as sports, military, and police (Low et al., 2020). It involves physically practicing domain-specific skills (e.g., self-defense and arrest skills, communication skills) under simulated stress with the aim to maintain or even improve performance under stress. As such, training under stress does not necessarily introduce a completely new or unfamiliar exercise. Rather, it enhances the existing training by introducing psychological pressure that will alter the trainee's emotional state (Low et al., 2020). Psychological pressure is defined as "any factors or combination of factors that increase the importance of performing well on a particular occasion" (Baumeister, 1984, p. 610) and is very likely to induce stress responses (Lazarus and Folkman, 1984). It is manipulated by increasing either demands of the task or consequences of the trainee's performance. In police service or training, many tasks contain consequences that have an immediate impact, e.g., an antagonist firing back at the officer upon performance errors (Nieuwenhuys and Oudejans, 2011).

The ultimate goal of training under stress is to train the ability to cope with stress while simultaneously executing skills or making decisions (Low et al., 2020). Therefore, it is distinct from stress inoculation training which also exposes trainees to situational cues to induce stress. Stress inoculation training aims to prepare individuals for stressful situations by diminishing the potential for a maladaptive stress response through the gradual, controlled, and repeated exposure to a stressor (Wiederhold and Wiederhold, 2008). In training under stress, stress responses are not necessarily reduced, but rather the utilization of mental effort despite the presence of stress is improved (Nieuwenhuys and Oudejans, 2011; Oudejans and Pijpers, 2009, 2010). In dealing with the affective elements in learning designs, the trainee is able to experience psychophysiological stress responses associated with the specific task and their effect on cognitive and motor performance (functionality). The trainee is encouraged to use these experiences to explore individualized strategies and functional problem solutions to cope with stress (action fidelity; Körner and Staller, 2018). Variability in behavior is explicitly allowed, since trainees might differ in their prerequisites (e.g., physical capabilities, past experiences, individual stress reactivity) and even the slightest changes in environment (e.g., darkness, limited space) and/or the trainee (e.g., position, balance) require functional adjustments ("no repetition in repetition", Schöllhorn et al., 2012). Through practice and experience, the trainee learns to enhance the stability of coping strategies and performance behaviors and thus increase his or her resistance to variable psychological perturbations. Therefore, as many practice trials as possible under variable circumstances should be conducted in training to allow generalization (Headrick et al., 2015).

Naturally, individual verbal, physical, cognitive, and psychological skills may change and optimize with increasing training and work experience (Landman et al., 2016; Nieuwenhuys, and Oudejans, 2011; Oudejans, 2008; Vickers and Lewinski, 2012). Therefore, scenario-based training under stress should expose officers to increasingly complex and demanding situational and emotional constraints (Di Nota, and Huhta, 2019). Training under stress has been shown to be equally effective for both novices and experts (Low et al., 2020), suggesting that appropriate amounts of constraints can already be introduced at an early stage in a trainee's development and should then be adapted as the trainee gains experience.

Importantly, when imposing emotional constraints in the learning environment, police trainers should take caution that emotional constraints do not overwhelm the officers to a point where they experience maladaptive stress that impedes their ability to retrieve and encode information effectively (see stress-

memory continuum; Di Nota and Huhta, 2019). Based on Yerkes and Dodson's (1908) seminal work, stress is assumed to influence learning and memory processes on an inverted U-shaped continuum. At moderate levels, stress even facilitates learning by promoting attentional arousal and encoding of novel information. Research has established a memory advantage for emotionally arousing events compared to neutral events (e.g., Payne et al., 2006) and inducing physiological stress responses immediately prior to or during learning improved learning outcomes (Cahill and Alkire, 2003; Cahill and McGaugh, 1998). However, extreme stress interferes with both encoding and retrieval processes (Shackman et al., 2006; also see Davis and Loftus, 2009; Hope, 2016), thereby impairing learning outcomes. In this sense, emotional constraints in training under stress should be aimed to be located at an optimal position in the middle of the stress-memory continuum (Di Nota and Huhta, 2019).

The principles of scenario-based police training following the recommendations for training under stress are summarized in Table 1.

Table 1. Principles of scenario-based police training following the recommendations for training under stress

Principle 1	Scenarios should be **representative of critical incidents** the trainee will typically face in their day-to-day duties.
Principle 2	Scenarios should **induce psychophysiological stress responses** allowing officers to discover and try out coping strategies to mitigate stress responses and effectively utilize mental effort.
Principle 3	**Optimal stress levels** should promote encoding of the learning experience.
Principle 4	Scenario-based training needs to be **individualized depending on the trainee's skill level** and experience, so that it requires effortful cognitive engagement.
Principle 5	**Many practice trials** are necessary to stabilize resistance to variable (psychological) perturbations.
Principle 6	Trainees should be exposed to **increasingly complex and demanding scenarios.**
Principle 7	**Constructive and concrete feedback** from qualified instructors allows learners to explore multiple behavioral options (including coping strategies) to successfully achieve the desired outcome in a controlled, safe environment.

(Araújo and Davids, 2011; Körner and Staller, 2018; Low et al., 2020)

Challenges in the Application of Scenario-Based Training Under Stress

Although scenario-based training is commonly practiced in police academies (Di Nota and Huhta, 2019), various open questions and challenges remain concerning its application. Some of these challenges result from a lack of (scientific) knowledge about the efficacy mechanisms, others from organizational constraints in the current training practice.

Challenge 1: Resource Intensity

Scenario-based training is highly resource-intensive (Di Nota and Huhta, 2019). Therefore, budget is a severe threat to adequate training. Many unique and relevant scenarios need to be developed to comply with the principles of representative, increasingly emotionally demanding, and challenging scenarios. This requires numerous, highly qualified personnel and space-consuming training facilities (e.g., different premises, accessible facades of urban houses and vehicles), including the costs of maintenance and adaptation for different circumstances. Nevertheless, solid training or shooting facilities offer limited

variability in scenario creation, leading to trainees' familiarity and habituation with a certain environment, although split-second decisions in novel situations are intended to be trained. Additionally, set-up and reconstruction of solid facilities is time-consuming, taking away valuable training hours (Cushion, 2018; Staller et al., 2020). Since training is limited, the principle of many practice trials is challenged. As a consequence, police officers demand more frequent and realistic training opportunities (Renden et al., 2015). To meet these demands, innovative training practices are warranted that allow diverse and flexible learning environments which can provide more on-task time during training.

Challenge 2: Optimal Stress Induction

To establish the principle of optimal stress level during training, police trainers would require knowledge about both optimal and elicited psychophysiological stress responses. The unawareness of stress levels during training puts trainers at risk to incorporate too extreme scenarios too early in the training process, which might negatively condition officers, resulting in decreased ability to perform well in similar scenarios in the future. Thus, the scenario content and/or situational constraints should not be randomly selected by the trainer. However, two major scientific knowledge gaps about (police) stressors, elicited stress levels, and their role in the efficacy of training under stress complicate the development of evidence-based guidelines: 1) how much stress should be elicited during scenario-based training to maximize learning outcomes, and 2) how can police trainers manipulate scenarios to achieve these optimal stress levels.

The scientific identification of these optimal stress levels is complicated because stress reactivity is highly situational and individual. People differ in their response to the same threat because of personal attributes, appraisals, coping strategies, social support, and past experiences. For instance, recent evidence shows that police officers have significantly higher baseline levels of cortisol relative to the general population (Planche et al., 2019), which might result in less pronounced cortisol reactivity to acute stress situations (Giessing et al., 2019, 2020; Strahler and Ziegert, 2015). Further, self-reported stress levels do not necessarily match physiologically measured stress levels (Campbell and Ehlert, 2012; Giessing et al., 2020). Thus, an individual's current position on the stress-memory continuum might be confounded by the individual and occupationally mediated differences in stress reactivity (Di Nota and Huhta, 2019).

But even if the optimal stress level of the trainee in a given scenario was known, police trainers would then face the challenge of how to manipulate the scenario content and its situational constraints so that it accurately elicits the desired stress level. So far, it remains unclear which situational constraints simulated in scenarios elicit which amount of psychophysiological stress responses. To meet the principle of representativeness, systematic and representative data about stress-inducing situational constraints, their occurrence probabilities in police service, and evaluations of their stress potential are necessary. This knowledge could result in a stress cue repository from which police trainers can draw valid stress cues to systematically manipulate the scenarios in accordance with desired stress levels.

Challenge 3: Feedback Options

The principle of constructive and concrete feedback in scenario-based training is repeatedly emphasized (Bennell et al., 2020; Jenkins et al., 2020; Rajakaruma et al., 2017) and observational case studies confirm police trainers spend a large part of the training time on explanations, demonstrations, and corrections (Cushion, 2018; Staller et al., 2020). Nevertheless, police trainers are criticized for providing lengthy,

corrective feedback that focuses too much on the precise imitation of a technical or tactical solution (Blumberg, et al., 2019; Staller et al., 2020). Following the idea of the ecological dynamics framework (Araújo and Davids, 2011; Körner and Staller, 2018), feedback should rather target the feasibility and effectiveness of individualized solutions to cope with the given context constraints. Instead of discussing the correct execution of technical skills in isolation, the perception, interpretation, and execution of the skills should be considered as a united process (cf. Nieuwenhuys and Oudejans, 2012, 2017) against the background of the situational constraints. In the current practice, lengthy, verbal feedbacks take away much time of the valuable training hours that could otherwise be spent for qualitative time-on-task (Staller et al., 2020). Additionally, feedback sessions are often conducted immediately after scenario completion, when trainees are still likely to be aroused (Andersen et al., 2018) and therefore, unable to focus on and internalize the feedback (Bennell et al., 2020; Jenkins et al., 2020). To provide trainees with adequate feedback on their utilization of coping strategies, non-intrusive feedback options during the tasks in the scenarios or guided feedback sessions after the scenarios are needed in police training. Augmenting feedback sessions with video material of the scenarios can reduce cognitive load in still aroused trainees or might allow the delay of feedback sessions to give trainees to time to recover from the stress levels during the scenario (Bennell et al., 2020; Jenkins et al., 2020).

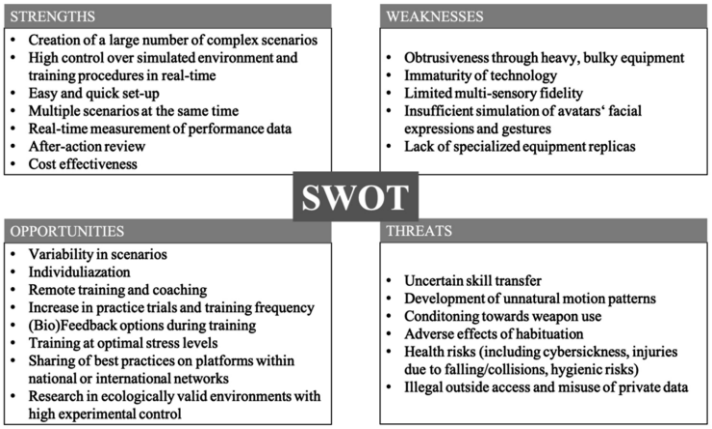
VIRTUAL REALITY: NEW DIRECTIONS IN SCENARIO-BASED POLICE TRAINING

Virtual Reality (VR) has the potential to address the current challenges of scenario-based police training while fulfilling the proposed principles of training under stress (see Table 1). VR provides a computer-generated simulation, in which the trainee can move through an artificial three-dimensional environment, interact with objects in this space or communicate with avatars. Through headsets consisting of a head-mounted display or specially designed rooms with multiple large screens, VR generates realistic images, sounds, and other sensations that simulate the trainee's mental and physical presence in a virtual environment. As the trainee interacts with and/or reacts to the environment, movement is captured by sensors, allowing the system to provide feedback.

Because of the promising properties of VR, law enforcement agencies, research groups, and technology companies are already discussing its implementation in police training curricula (e.g., Europeans Union's Horizon 2020 project SHOTPROS, grant No. 833672, https://shotpros.eu). VR promises to enable a safe, immersive, and cost-effective way of experiential learning in varied and complex environments. However, the main challenge of VR training lies in its questionable efficacy and transferability to real-life incidents. Although there are first attempts to investigate the efficacy of VR (stress) training in first responders (Bertram et al., 2015; Moskaliuk, Bertram, and Cress, 2013; Caserman, Cornel, Dieter, and Göbel, 2018; Muñoz et al., 2020), it cannot be considered empirically validated yet (Anderson et al., 2019; Di Nota and Huhta, 2019). Nevertheless, police-specific VR solutions are already on the market (for an overview see SHOTPROS, 2020). To direct an evidence-based integration of VR in police training and related research, a SWOT analysis was conducted to identify the strengths, weaknesses, opportunities, and threats when applying VR in police training. While the SWOT framework was originally used as a tool to analyse market forces impacting the standing of companies, it has been utilized successfully in academia to analyse the application of emerging technologies in a specific field (e.g., Düking et al., 2018; Engelbrecht et al., 2019). A summary of the strengths, weaknesses, opportunities, and threats can

be found in Figure 1. The following sections will discuss the results of the SWOT analysis in relation to the current challenges in police training: (1) the potential cost-effectiveness of VR due to its flexibility, (2) the potential for (optimal) stress induction in training, and (3) the potential for concrete, interactive feedback sessions after the scenarios.

Figure 1. Strengths, weaknesses, opportunities, and threats of the use of VR in police training.



Unlimited Possibilities?

By virtue of its nature, an almost infinite number of complex scenarios can be designed and manipulated in VR (Düking et al., 2018), which are difficult or immensely resource intensive to simulate in the real world. Police trainers have higher control over the training procedures (e.g., order of events, level of complexity, reduction of risks) and can configure scenarios according to their needs and training aims. As such, VR training offers a great variability of training scenarios, so that a range of examples and permutations of conditions can be provided as learning opportunities within a single training session. Instead of repeatedly training the same procedure under the same conditions, trainees learn to flexibly adapt their skills to varying conditions (for a good example of implementation see Caserman et al., 2018).

To fully utilize this potential, it is important to allow for enough variability in the action options ranging from personal communication, physical self-defence skills, pepper spray, to firearms. Traditionally, skills for weapon use and defence tactics are overrepresented in police training (Blumberg et al., 2019). Certain training methods (e.g., colour ammunition training with full body protection equipment) imply the expectation of firearm use even before the training scenario begins, limiting the number of decisions trainees (think they have to) make. To ensure that VR training does not become part of the tradition of yet another shooting training, it should promote the use of a variety of skills including decision-making for these options. The most prominent police intervention is communication. Certainly, integrating multiple real and simulated characters in the scenarios and the use of voice commands (e.g., "Hands behind

your head!") facilitate the interaction with avatars. However, in the applied practice, the insufficient simulation of facial expressions and gestures are often mentioned as a severe limitation, as they are important information sources for emotion and social recognition in high-stress situations (Damjanovic et al., 2014). In clinical research, there are first findings that VR training can enhance emotion and social recognition in populations with psychological disorders (Didehbani et al., 2016; Kandalaft et al., 2013; Nijman et al., 2019; Peyroux and Franck, 2016; Rus-Calafell et al., 2014; Yang et al., 2017). While these training programs usually focus on the simulation of avatars without providing context, future efforts in the development of VR police training should aim to integrate high-fidelity avatar simulations in complex environments.

VR can handle the variety of training scenarios in the same location, only requiring relatively modest open space. With user-friendly interfaces and well-educated trainers, VR scenarios are easily set up and several officers can train simultaneously in the same scenarios, which saves training time for on-task experiences and can result in larger numbers of repetitions per training session (Düking et al., 2018). While the initial costs for the purchase of the equipment and the development of training scenarios may be high, the relatively cheap adaptation of different scenario contents, the lower costs for maintenance, and the portability of the equipment to different training sites might be cost-effective. Additionally, VR might even allow remote training: either individually at any time fitting the trainee's everyday schedule or with multiple trainees that may be geographically apart. Consequently, remote training might reduce the logistic obstacles (e.g., long travel distances to appropriate training centers including travel expenses and time) and therefore, increase training frequency. Equipping every police department or individual police officer with the potential to train in a wide range of scenarios at a fraction of the cost could greatly increase the police officers' preparedness for critical incidents on police duty.

Despite the supposedly unlimited possibilities, VR training should rather supplement the existing training practices than replace them (Haskin et al., 2020). One major concern in the application of VR in police training is the potential development of unnatural patterns of motion (e.g., in the shooting technique), partly due to the obtrusiveness of bulky, heavy equipment (Düking et al., 2018) or imprecise replicas of police equipment. Therefore, the training aims of VR need to be clearly outlined before the implementation in police training. Clearly, traditional training is much better suited to teach motor movement sequences such as shooting or intervention techniques. However, traditional scenario-based training does not typically provide (or is too expensive to support) the full context that officers need to adequately assess the situation. Therefore, it is often necessary that the trainer verbally describes the context of the simulated incident based on the role play script. By this, the trainer might draw attention to details of the incident – potentially giving away the critical learning experiences – that might not have been noticed by the trainees themselves (Haskin et al., 2020). VR offers the ability to simulate very detailed visual and audio contexts containing both explicit and subtle cues. Therefore, VR can serve the training objectives of searching for hazards (perception), assessing the situation (interpretation), and taking appropriate actions (action; cf. Nieuwenhuys and Oudenjans, 2012, 2017). As such, VR should serve as a bridge between existing, empirically validated training practices and novel learning opportunities in representative environments.

Artificial Environments – Real Emotions?

VR has been receiving a lot of attention due to the high level of immersion which allows ecological validity in the training scenarios. In police training, the immersive VR might be an especially valuable

tool since it can simulate potentially dangerous scenarios which are difficult or impossible to simulate in the real world for financial, personnel, or ethical reasons. As highlighted in the ecological dynamics framework (Araújo and Davids, 2011; Körner and Staller, 2018; Headrick et al., 2015), a realistic training environment that accurately portrays real-life threats and stimulates the corresponding psychological responses is an essential part of preparing officers for their working conditions in real life. Therefore, authentic VR simulation is needed to produce a close proxy to the real world and tasks. Research has already shown that virtual environments and cues can successfully induce stress and the corresponding psychophysiological responses in established stress protocols (e.g., Trier Social Stress Test; Zimmer et al., 2019) and in high-stress domains, such as sports (Sanz et al., 2015; Stinson and Bowman, 2014), and police (Groer et al., 2010, Muñoz et al., 2020). Changes in the audio-visual environment in a virtual performance setting (e.g., display of score boards, virtual opponents or spectators or acoustic feedback) elicited self-reported stress levels (Sanz et al., 2015) and anxiety (Stinson and Bowman, 2014) as well as galvanic skin responses (Stinson and Bowman, 2014). In a sample of police officers, two types of shooting scenarios elicited various psychophysiological stress responses, including increases in salivary cortisol, alpha-amylase, secretory immunoglobulin A (sIgA), and interleukin-6 (Groer et al., 2010). All in all, this research suggests that specific cues in virtual reality scenarios produce psychophysiological stress responses, mimicking occupational stress.

In the body of VR literature, there is an ongoing debate about which factors influence the effectiveness of VR to elicit stress responses. The concepts of immersion and presence are defining elements. As defined by Slater and Wilbur (1997), immersion refers to the objective level of sensory fidelity, and presence refers to the user's subjective psychological response to a VR system. It is assumed that higher levels of immersion lead to higher levels of perceived sense of presence and, therefore, lead to stronger psychophysiological (stress) responses. As such, it might be concluded that the most advanced, technologically immersive system possible should be designed to maximize user presence. Therefore, the immaturity of the technology and the resulting cybersickness are considered as weaknesses of VR training (Engelbrecht et al., 2019). Therefore, great developmental efforts have been put into improving frame-rate, tracking, field of view, refresh rate, latency, and resolution over the past years (Cummings and Bailenson, 2016). However, high immersion hardware comes with certain costs, e.g., financial expenses, greater cumbersomeness, and calibration requirements. Therefore, the benefit of newer or additional technology must be balanced by practical restrictions and their actual addition to the trainee's sense of presence. A recent meta-analysis found that tracking level, stereoscopy, and field of view have a stronger impact on user presence compared to other features, particularly image quality, resolution, and sound (Cummings and Bailenson, 2016). Importantly, however, immersion is not limited to visual and audio fidelity. Multi-sensory VR simulations including haptics (e.g., vibration for collision feedback, pain stimuli when being hit or shot) or olfactory stimulation (e.g., smell leaking gas, smell of alcohol, strong body odour) can increase immersion and serve as important cues for appropriate risk assessment in high-stress situations. Since policing is a team effort, multi-user fidelity in the VR is warranted that enables cooperation in the training scenarios. A current challenge in the multi-user fidelity is the spatial localisation of colleagues through auditory stimuli. For instance, footsteps of the colleagues are not audible and communication via headsets does not convey any information about the location of the speaker. Besides these technical aspects, personal factors also determine the extent of stress experience (Campbell and Ehlert, 2012). By allowing a great diversity in scenarios, VR can account for this individuality.

In order to gather information about the individual stress experience, there are already first (successful) attempts to measure and track psychophysiological stress responses and training progress of police

officers in the recent literature, including the measurement of pupil diameter (Bertilsson et al., 2019a, 2019b), brain waves (Muñoz et al., 2020), and heart rate variability (HRV; Brisinda et al., 2015; Muñoz et al., 2020; Thompson et al., 2015). Among those, HRV is a very promising method, as it is easy to administer (e.g., through chest belts) and has been shown to provide reliable biofeedback in relatively high temporal resolution (i.e., 30 sec intervals; Brisinda et al., 2015). A potential disadvantage of HRV is susceptibility to artifacts and biases through physical activity or movements (e..g, walking or sweeping arm movements). However, it is possible to perform ambulatory measurements of HRV while controlling for respiration and physical activity (Laborde et al., 2017; e.g., Baldwin et al., 2019). During various high- and medium-stress realistic police scenarios, HRV parameters even differentiated between rest and stress conditions and between mental (i.e., shoot/no shoot challenge at a simulator) and physical stress (i.e., effort with bicycle ergometer; Brisinda et al., 2015). According to the neurovisceral integration model (Thayer et al., 2009), HRV reflects an individual's capacity to effectively organize physiological and behavioral resources in response to environmental demands. Higher resting HRV allows quicker adaptability and greater behavioral flexibility in demanding environments, while individuals with low HRV might have reduced capacity to respond efficiently (Thayer et al., 2009). Such evaluation is of particular importance in the context of police work, which is characterized by diverse work stressors requiring a large repertoire of fast behavioral responses. Thus, the study of real-time psychophysiological stress markers during realistic VR scenarios might be an objective method to assess the extent of mental effort the trainee is currently investing. As a tool to monitor the trainee's training performance, it provides the trainers insight into the momentary stress level of the trainees and allows them to adapt the difficulty of the task to the trainees' abilities in real time (Düking et al., 2018; Haskins et al., 2020). As a consequence, motivation to keep practicing and stay cognitively engaged is maintained by increasing the task difficulty based on real-time psychophysiological data. However, further (field) research is needed to support the validity and reliability of psychophysiological stress measurements in VR scenarios to guide appropriate interpretation of the outcomes.

Nevertheless, the remaining difficulty is that it is still unclear which stress levels should be elicited during training for optimal learning outcomes and which cues are effective in doing so. While this difficulty concerns both traditional scenario-based and VR training, VR offers novel, promising possibilities for research to answer these questions (Düking et al., 2018; Haskin et al., 2020). Providing high experimental control, potentially stress-inducing situational constraints can be systematically manipulated and tested in ecologically valid environments. In VR, most factors can be held constant (e.g., suspect's behavior which is not possible with live actors), while only altering the factors of interest (e.g., appearance of the suspect, acoustic environment). Especially in the context of police, in which it is impossible to predict and unethical to manipulate real-life critical incidents (Giessing et al., 2019), VR and its immersive contexts can advance research by assessing psychophysiological and behavioral data in representative environments (Düking et al., 2018). By doing so, VR-based research can help to identify optimal stress levels during scenario-based training by manipulating trainees' stress levels through the systematic manipulation of situational cues. Additionally, a high frequency of exposure to stressful training scenarios might habituate trainees to threatening situations over time, thereby aiding the extinction of potentially adaptive stress responses for optimal performance. Therefore, research into the intensity and frequency of VR training is needed to ensure that VR training does accomplish the development of effective coping strategies, but not the extinction of adaptive psychophysiological stress responses (Engelbrecht et al., 2019).

Optimal Feedback Opportunities?

In accordance with the ecological dynamics framework (Headrick et al., 2015), the key learning objectives in VR police training should be understanding stress responses, identifying their impact, learning and applying coping strategies to mitigate the impact of stress, and recognizing when and where to seek support (Bouchard et al., 2012). However, the education of coping skills to officers has been considered a central challenge in police training as some officers show resistance to the practice and use of tools developed for the purpose of stress regulation (Papazoglou and Tuttle, 2018). Thus, it is recommended to introduce tangible coping strategies that can be easily applied within their daily work routines instead of teaching coping strategies outside the work context (Papazoglou and Andersen, 2014; Papazoglou et al., 2020). With various feedback options during and after training scenarios, VR might offer an ideal training ground with novel possibilities to directly integrate coping strategies in police training (Bouchard et al., 2012). Real-time tracking during training can help trainees to become aware of changes in their stress levels, attention, interpretation. The awareness for these processes gives them the opportunity to discover effective coping strategies to mitigate these changes, and the potential of repetitive actions (often not feasible in real-life scenarios) enables their immediate application. Additionally, real-time data collection can direct police trainers' feedback to the individual weaknesses, not only in a post-hoc analysis, but also immediately by displaying relevant metrics for improvement and engagement during the scenario (Engelbrecht et al., 2019).

During training scenarios, psychophysiological biofeedback might facilitate police trainers' efforts to individualize the scenarios. Likewise, trainees might benefit from being continuously informed about their stress level. HRV biofeedback has been shown to be effective in reducing stress and anxiety both in real-life settings (for a recent meta-analysis see Goessl et al., 2017) and in VR (Rockstroh et al., 2019). So far, environments with restorative qualities (e.g., nature settings) have been simulated in VR for biofeedback training (Annerstedt et al., 2013; Gaggioli et al., 2014; Rockstroh et al., 2019), as these environments are assumed to replenish voluntary attention capacity (Attention Restoration Theory; Kaplan and Kaplan, 1989). Following the recommendation of integrative psychological skills training (Papazoglou and Andersen, 2014; Papazoglou et al., 2020), embedding biofeedback in experiential, high-stress scenarios might help police officers to better detect signs of stress themselves while engaging in their occupational tasks. These signs can then serve as cues to use appropriate coping strategies. During the imagery of stressful police scenarios, HRV-focused trainings with police officers have successfully reduced stress responses (Andersen and Gustafsberg, 2016; Andersen et al., 2015; Arnetz et al., 2009, 2013). The advantage of biofeedback in VR might be the increased immersion, which might result in more realistic experiences, higher training engagement, and better transferability of the skills. The fundamental mechanism of biofeedback training is the operant conditioning through positive reinforcement (cf. Gaume et al., 2016, Sherlin et al., 2011). The integration of feedback parameters into the virtual environment might result in greater awareness for the feedback on the corresponding stress levels (e.g., annoying music in a domestic violence case becoming quieter with decreasing stress levels; Bouchard et al., 2012). Thus, biofeedback during scenarios might reinforce the use of appropriate coping strategies and increase perceived self-efficacy when mastering occupationally relevant, stressful tasks. By negative conditioning, biofeedback can even be used to force trainees to use coping strategies by reducing the trainee's possibilities for efficient interaction in case of high stress levels. For instance, the trainee's field of view can progressively be reduced, as stress levels increase (Bouchard et al., 2012). While (HRV)

biofeedback has been shown to be effective in reducing stress in police officers, more research is needed on how it relates to performance and how it can be implemented in scenario-based VR training.

Another potential applied use of VR lies in the ability to improve goal-directed attention to specific information sources during the scenarios (Craig, 2014). In the ecological dynamics framework (Araújo and Davids, 2011; Körner and Staller, 2018), the ability to perceive opportunities for goal-directed behavior is predicated on an individual's ability to detect information in a performance environment relative to his/her existing action capabilities. The importance of an efficient visual search rate, enhanced selective attention allocation, an extended visual span, and scan pattern systematicity for expert performance was recently demonstrated in a meta-analysis (Brams et al., 2019; for a review on gaze behavior training in police samples see Heusler and Sutter, 2019). Information processing can be optimized by selectively allocating available attentional resources to task-relevant stimuli and ignoring irrelevant stimuli (Nieuwenhuys and Oudejans, 2012, 2017). Hence, (visual) cues and sight lines can make action opportunities in the environment more explicit and guide visual attention processes. As the trainer is in full control over the presented virtual environment, salient cues could appear in areas of interest helping trainees to focus on the right spots for gathering relevant information at the right time (Craig, 2014).

After training scenarios, the after-action review (i.e., replay of the scenario) offers various feedback options, as it can be enriched with objective and automated performance measures collected during training, e.g., sighting lines, snake lines (i.e., paths walked by the characters), visual fields or perspective taking of various avatars. Given the concrete material to draw on, VR can make the feedback less abstract, while potentially reducing cognitive load during, which might be particularly relevant in feedback sessions immediately after scenario completion when trainees might still be aroused (Bennell et al., 2020; Jenkins et al., 2020). Therefore, the after action-review incentivizes trainees to reflect on their performance based on instructor feedback and self-assessment. In the current debriefings, police trainers often experience that arguments arise if specific cues or actions were visible for the trainee and/or suspect from their point of view. Through the display of visual fields or perspective taking of various avatars, these arguments can be enriched with a greater variety of experiences. VR can recreate different viewpoints of the same event (e.g., allocentric – the trainer's perspective; egocentric – the trainee's perspective or perspective of all other involved avatars), so that trainers and trainees can see an event (replayed) from other perspectives. Seeing an event unfold from different viewpoints and augmented with sighting lines and snake lines might help to spot weaknesses in the tactical movements and positions and in turn, develop and improve tactical strategies (Craig, 2014). As experiences can be visually shared, it might encourage reflection, active participation, and interaction, thereby fostering the learning experience (Bennell et al., 2020; Rajakaruma et al., 2017).

Training data could be stored in specific databases to monitor the training progress of each trainee and/or to share best practices within national or international networks. These best practices can include scenario set-ups serving specific training objectives and after-action reviews of particularly successful solutions to specific scenarios. This kind of knowledge exchange might help to standardize training and intervention procedures which in turn facilitates teamwork across police departments, agencies, and countries. However, intensive data collection must be balanced against data privacy (Spiegel, 2018). Given the nature of data that may be gathered via VR, more delicate personal information will be available to law enforcement agencies including physical features, motor responses, eye-movement patterns, and physiological (health) information of their employees. Law enforcement agencies might misuse the information for health and performance analyses in the selection of personnel. Additionally, digital data is always vulnerable to hacking, which might reveal both sensitive personal information or organiza-

tional information about tactics and procedures to the public. Therefore, ethical implementation of VR in police training also requires secure data storage and the development of data protection regulations (e.g., regarding the intended use, access rights, and storage period) to protect data from outside access and misuse (Spiegel, 2018).

CONCLUSION

To summarize, VR systems seem to be a promising tool for improving certain aspects of police training and related research, including coping strategies, situational awareness, decision-making, and creative behavior. Police training requires realistic scenarios in which police officers can learn to attune and adapt to the situational constraints of critical incidents on police duty. So far, scenario-based training is limited by its resource intensity, restricted variability in the scenario set-up and few feedback options. VR has the potential to overcome these challenges by offering high control over flexible learning environments in which scenario content and feedback options can be systematically varied in real-time. Although VR is still a growing technology, police-specific VR solutions are already on the market and law enforcement agencies have started to implement VR in their training curricula. Nevertheless, VR comes with several weaknesses and threats that jeopardize the efficacy of VR training. Therefore, it is crucial to design systems that meet the specific training principles and supports the desired didactical approach. Defining requirements and practical guidelines will help law enforcement agencies to successfully integrate VR in their current training curricula (see Murtinger et al., 2021). These guidelines need to build upon knowledge about the necessary degree of simulation fidelity, optimal stress levels, valuable feedback features, and optimal frequency and duration of VR training. Clearly, more research is warranted to elucidate the learning mechanisms of training under stress and the role of stress levels. VR can advance the current state of research by enabling innovative studies and field trials for examining, validating, and evaluating relevant human and situational factors of police performance and training under stress. Since evaluations of the VR efficacy in police training and its transferability to real-life behaviour are still outstanding, close collaboration among law enforcement, technology companies, and research institutions can help to identify and meet needs for further technological and scientific developments of VR training. This chapter offers a starting point for policy makers, police trainers, as well as researchers to build upon when implementing VR in police training.

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KEY TERMS AND DEFINITIONS

Coping Strategies: Allow to maintain performance under stress by investing mental effort to master, minimize or tolerate stress responses and their impact on cognition and action.

Ecological Dynamics Framework: A theoretical framework to explain the acquisition and transfer of adaptive human behaviors to a specific performance context. In representative learning environments, the trainee can adapt and attune to the constraints of the performance context.

Representativeness: The quality feature of a simulation that indicates how well the essential properties are reflected. Properties should be sampled from the criterion environment, achieving similar occurrence probabilities in the learning and criterion environment.

Scenario-Based Training: An immersive learning environment in which trainees are exposed to realistic and occupationally relevant stressors, which allows the integrated practice of verbal, physical, and cognitive skills under realistic circumstances.

Situational Constraints: Factors in the environment which limits action possibilities of an individual.

Stress: An unpleasant state that arises when an individual perceives his/her coping resources as insufficient to meet the environmental demands. It results in the activation of the sympathetic adrenomedullary system and the hypothalamo-pituitary-adrenal axis.

Training Under Stress: The practice of domain-specific skills under simulated stress (by introducing affective elements in the learning environment that elicit stress) with the aim to maintain or improve the performance in a stressful performance context.

Virtual Reality (VR): A computer-generated simulation of a three-dimensional, immersive environment in which the user can interact with objects and communicate with avatars using electronic equipment, such as head-mounted displays, multiple large screens and motion capture sensors.

Appendix A5 – Manuscript 5

Note:

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Mapping demands: How to prepare police officers to cope with pandemic-specific stressors

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Abstract

Frequent and varied training of police officers is crucial to optimally prepare them for the challenges they face in their police work and allow them to cope with these demands effectively. The Horizon 2020 project "SHOTPROS" aims to develop a training program in Virtual Reality (VR) to train appropriate decision-making and acting capabilities of police officers in high-stress situations. The current COVID-19 pandemic can be considered a prime example of such a high-stress situation. Therefore, the aim of the present article is to re-analyse data from a longitudinal survey among 2567 police officers across Europe to identify pandemic-related demands experienced by the participating officers during the first COVID-19 lockdown that can be integrated and trained in (virtual) scenario-based training to better prepare police officers for the current and potentially future pandemic outbreaks. Following the constraints-led approach to training, pandemic-related demands are categorized as task, environmental, and individual constraints to provide police trainers with a toolkit how to change and manipulate training scenarios according to the trainees' needs. Offering high control over training procedures, VR might be an effective tool to incorporate pandemic-related stressors into current training practices.

Keywords: COVID-19, police training, constraint-led approach, stress, virtual reality

Mapping demands: How to prepare police officers to cope with pandemic-specific

Police training is of utmost importance to prepare officers for the challenges they face in their police work in the field and to enable them to cope with the work demands effectively. In order to be effective as a learning setting, police training should (a) be constructively aligned with the demands in the field, and (b) provide police officers with opportunities to learn what is needed to cope with the demands. As the COVID-19 pandemic and the resulting governmental measures continue to pose unprecedented challenges on European street patrol officers, they should be able to easily transfer the skills they acquire in training into real-life situations. Recently, the longitudinal study "SHOT-COVID19", as part of the project SHOTPROS under European Union's Horizon 2020 Framework, investigated the work demands, coping resources, and stress of European street patrol officers during the first months of the COVID-19 pandemic (Frenkel et al., 2021). The aim of the present article is to re-analyse this data to identify pandemic-specific demands that can be systematically translated into police training to better prepare police officers for current (and future) pandemic-related situations in the field.

SHOTPROS: Improving performance of European police officers by developing VR enhanced training

The European Union's Horizon 2020 project SHOTPROS (2019-2022; https://shotpros.eu/)[13] aims at improving the performance of police officers through the training of decision-making and acting (DMA) in Virtual Reality (VR) settings, resulting in better abilities to keep control over threatening situations and a decrease in excessive use of force occurrences with potential casualties or collateral damage. To this end, SHOTPROS investigates the influence of human factors (HFs) on the DMA of police officers under stress and in high-risk operational situations. This knowledge enables the design of effective

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training guidelines for police training in DMA under stress. This will ultimately lead to the development of a HF-rooted training curriculum and a corresponding VR-solution to be able to systematically manipulate the influence of HF on police officers' stress and DMA during training in order to complement 'traditional' live simulation training.

Policing in high-stress situations

As a first step in the identification of relevant HF that impact police officers' DMA, a total of 60 police officers and trainers participated in six workshops, one in each of the law enforcement agencies (LEAs) representing the SHOTPROS consortium (from Belgium, Germany, the Netherlands, Romania, and Sweden). During each workshop, one focus group was dedicated to the exploration of factors that participants considered to have a (negative) influence on their stress levels and their DMA capabilities during operational situations.

Results of these focus groups showed that the stressors could be assigned to four distinct categories. The first category comprised *contextual factors*, i.e., elements that are present within the environment or situation of the specific police intervention. Examples of such factors are threats to the officers' physical integrity, the presence of bystanders (e.g., interfering with their police work), sensory overload (e.g., through noises, smells, many visual cues), unclear circumstances, and a loss of control over the situation at hand. The second category consisted of *organisational factors*, which are elements that are specific to their LEA organisation. Examples of organisational factors are feeling a lack of support or appreciation by colleagues or superiors, personnel deficits, different and changing rules and regulations, and lack of training. The third category comprised *individual factors*, which are personal characteristics that differentiate between individual police officers (e.g., lacking important skills, personality, personal stressors, and physical or mental strain). The fourth category contained *societal factors*, which addresses the fear of negative media coverage and loss of good reputation of the police as an institution or of themselves as police officers.

These four categories of factors are assumed to influence police officers' stress levels in a given situation, and as such can have an impact on the quality of their DMA capabilities and work performance.

Policing during the COVID-19 pandemic

The rapid emergence of the COVID-19 pandemic and the subsequent lockdown in the beginning of 2020 have confronted police officers all over Europe with a new and unknown challenge in real-life. During the pandemic, LEAs have played an important role in trying to minimise the transmission of the disease, securing public order and keeping communities safe (Brito et al., 2009). Simultaneously, the unprecedented strict governmental measures that had been enacted to protect citizens' health have been increasingly challenged on political, economic, and legal grounds (Mohler et al., 2020; Stogner et al., 2020). In their responsibility to enforce these measures, street patrol officers have been confronted with various novel challenges: The risk of infection as a constant threat to officers' physical integrity, changing governmental measures leading to a shift in calls for services, numerous alterations in policing protocols, high(er) workload due to infected and quarantined officers and more frequent encounters with anxious or intransigent individuals aggravated by the fear of contagion, economic uncertainty, and isolation (Drake & Altheimer, 2020; Jennings & Perez, 2020; Stogner et al., 2020). As such, policing during the COVID-19 pandemic can be considered a "critical police incident" (although of longer duration and larger geographical impact than usual police incidents; Jennings & Perez, 2020), requiring the officers to respond to novel, uncertain, uncontrollable, and threatening situations (Stogner et al., 2020). Therefore, the pandemic constitutes an opportunity to (1) investigate the influence of the above-mentioned four categories of factors (contextual, organizational, personal and societal) on police officers' stress, to (2) identify perceived coping resources to meet pandemic-specific demands, and (3) to translate these results into specific recommendations for police training.

To this end, a three-wave longitudinal study was conducted with police officers from various European countries reporting on their work stressors, coping resources and perceived stress levels during the first months of the COVID-19 pandemic (Frenkel et al., 2021).

Methodology of the study

The observational study was conducted online at four measurement points throughout an 11-week period during the COVID-19 pandemic from March 27, 2020 to June 5, 2020. Participating LEAs were recruited through the SHOTPROS consortium and its networks. To examine a large, diverse sample of officers, these LEAs widely distributed the survey online through mailing lists. In a longitudinal approach, each LEA participated at three measurement points (except the Dutch LEA that participated once) with a survey period of one week and two weeks in between survey periods. Due to internal approval procedures, LEAs started the online survey at different measurement points.

The sample consisted of 2567 police officers from six participating LEAs in five different countries, with Austria (n = 1415; 55%) achieving the highest number of participants, followed by Germany (n = 711; 28%), Switzerland (n = 325; 13%), the Netherlands (n = 76; 3%) and Spain (n = 40; 1%). In total, 3455 questionnaires were completed with an average of 1.35 (SD = 0.65) questionnaires per participant. The average participant was 36.69 years old (SD = 11.64) and had 17.22 years of work experience (SD = 12.69). Seventy-seven percent of the participating officers were male and 60% of participants were working in field service. The Social and Societal Ethics Committee of the KU Leuven provided ethical approval for this study (approval number: G-2019 081712). Informed consent was obtained from the participating officers. Participants received no financial compensation.

In a mixed method approach, the survey included quantitative and qualitative items. We repeatedly assessed police officers' perceived stress and fatigue (both measured with a

single item) and mood (subscales: *valence, energy, calmness;* Wilhelm & Schoebi, 2007), which collectively represented the strain they experienced (as confirmed by a Principal Component Analysis). To account for the nested data structure, three-level growth curve models assessed changes in strain and its relation to appraisal of the COVID-19 pandemic (as *stressful, challenging, controllable,* and *threatening*), emotion regulation (subscales: *adaptive and maladaptive emotion regulation*; Brans et al., 2013), preparedness through training (measured with a single item) as well as police officers' sex and years of working experience. To add context to the findings and to explore lived experiences, free response answers about officers' main tasks at work, private and work stressors and crisis measures and prevention as well as wishes for support were analyzed using the deductive category assignment in the qualitative content analysis according to Mayring (2014). For a more detailed description of the methodology, see Frenkel et al. (2021).

Summary of the initial results of the study

The final model included three levels (Level 1: country, Level 2: participant, Level 3: measurement point), with sex and work experience as Level 2 predictors and weeks since lockdown, appraisal of the COVID-19 pandemic, adaptive and maladaptive emotion regulation, and preparedness as Level 1 predictors. The intraclass correlation of the final model was 0.72, meaning that 28% of the variation in strain occurred within each individual, 66% between individuals and only 6% between countries. This finding suggests that police officers' strain is rather determined by interindividual differences (i.e., personal factors) than by differences between countries or LEAs (i.e., organizational and societal factors). On the first day of the lockdown, an average police officer had a rather medium strain level of 3.56 on a scale ranging from 1 to 7 ($SE = 0.16$, $p < .001$). A slight decrease (Estimate = -0.02, $SE = 0.01$, $p < .01$) of the strain level by 0.24 over three months after the lockdown was observed. Since officers generally experience elevated stress levels (Allison et al., 2019; Giessing et al.,

2020; Planche et al., 2019; Violanti et al., 2016) and changes in strain are rather small, it seems plausible to assume that the "average" officer was only mildly affected by the pandemic, although our data allows no direct comparison with pre-pandemic stress levels. Nevertheless, given the large individual differences in strain, Level 2 and Level 3 predictors can help to identify the participants that are at risk to show high levels of strain. Being female (Estimate = 0.22, *SE* = 0.06, $p < .001$), having less work experience than the average 17 years (Estimate = 0.01, *SE* < 0.01, $p < .01$), feeling unprepared (Estimate = 0.10, *SE* = 0.01, $p < .001$), appraising the pandemic to be stressful (Estimate = 0.46, *SE* = 0.06, $p < .001$), and using maladaptive emotion regulation strategies (i.e., rumination and suppression; Estimate = 0.16, *SE* = 0.03, $p < .001$) were significantly associated with strain, predicting higher strain levels.

Thus, the quantitative analysis demonstrated that personal factors, i.e., sex, appraisal of the pandemic, and emotion regulation, significantly contributed to police officers' stress. From the qualitative analysis of the officers' free response answers, two contextual factors emerged as major work stressors: risk of infection as a threat to the officers' integrity and information overload. While these findings are in line with theories that conceptualize stress as a person-environment transaction (Lazarus & Folkman, 1983), our analyses revealed that also organizational and societal factors contribute to the perception of work stressors. For instance, the risk of infection was perceived to be a result of or exaggerated by the lack of availability of personal protection equipment within the organization (i.e., organisational factor). Concerning the information overload, the daily changing governmental regulations and inadequate communication within the organization have been mentioned as a societal and organisational factor, respectively.

At the same time, police officers' reports on effective crisis measures and wishes for support showed that these HF can also be interpreted in terms of protective factors. As an

organisational protective factor targeted at the risk of infection, officers suggested that LEAs should logistically prepare for (future) pandemics through stockpiling personal protection equipment, having plans for personnel adjustments (e.g., 50/50 work plan, remote work), and altering policing procedures (e.g., limiting public access to police stations). To address the information overload, governments can reduce police work stress during pandemics on a societal level by legislating unambiguous regulations and effectively communicate them through the media to increase public compliance.

Importantly, both the quantitative and qualitative results of the present study have highlighted training and work experience as important HFs. It is impossible to completely remove stress from police work (during pandemics), as the experience of stress is intrinsically linked to being a police officer. While the above-mentioned practical recommendations might specifically target the perceived challenges and demands of the first lockdown, preventive (stress) training can prepare officers for both the acute and long-term impacts of pandemics on police work and any other high-stress situation. In the survey, police officers reported that they had acquired various skills in scenario-based situational response training that proved to be effective in their police work during the pandemic: (1) the automatism of keeping sufficient distance from the police vis-à-vis as a mean of self-protection, (2) target-oriented communication, especially with upset, anxious or mentally unstable individuals, (3) the ability to make quick decisions, and (4) stress regulation in critical situations. These findings suggest that certain skills already integrated in police training curricula have indeed been utilized by the police officers during the COVID-19 pandemic. However, the transferability of skills into the field could be further increased by integrating pandemic-specific demands into police training, following a constraints-led approach for training under stress (Giessing, 2021; Giessing & Frenkel, in press; Körner & Staller, 2020b).

Integrating pandemic-specific demands into police training

The police officers' reports in the present study provide valuable insights that can be used to design (VR) training settings that are representative for the situations that officers might experience in the field during pandemics. Therefore, we have re-analysed the officers' reports on work stressors to identify concrete examples of pandemic-specific demands within the major themes of risk of infection and uncertainty of action. By systematically implementing and manipulating demands in simulation training that are representative of these stressors, police training allows for the development and refinement of individual functional behaviors that help a police officer to cope with these stressors in the field.

From the perspective of police trainers, the demands can systematically be implemented and manipulated using a pedagogical concept called constraints-led approach (Körner & Staller, 2020a, 2020b). This approach builds on the premise that human behaviour is constraints-led, conditioned by the interplay of individual and environmental factors, which act as constraints (Renshaw & Chow, 2019; Torrents et al., 2020). It distinguishes between three categories of constraints that can be purposefully manipulated by the police trainer in order to allow trainees to experience the demands that they would also encounter in the field and to perform functional solutions to the demands posed. The three categories are: (1) task constraints, (2) environmental constraints and (3) individual constraints.

Task constraints refer to the specific factual and operational structure of the task, which is reflected in service regulations and guidelines. Pandemic-specific task constraints involve the application (and knowledge) of current COVID-19-specific regulations and operating under changing and recently implemented guidelines and procedures.

Environmental constraints include changing ambient conditions such as temperature, the spatial situation, the nature of the ground, the presence of people, and objects or light conditions. The current results show that pandemic-specific environmental constraints are (a) policing in confined spaces where the risk of infection is higher and (b) interacting with

individuals that have specific characteristics or display specific behaviours. These include the obvious display of COVID-19 symptoms, being part of a COVID-19 risk group, the noncompliance with and/or constant and repeated violation of the COVID-19 specific regulations (e.g., not wearing face masks or maintaining physical distance).

Finally, *individual constraints* refer to individual prerequisites of the police officer. On the one hand, individual constraints are of a structural nature that is relatively constant and less variable, such as body size or weight. On the other hand, they include situational initial states such as the motivation, intentions, or emotional states, that is, factors that can change from one moment to the next within persons. Concerning the pandemic-specific stressors, constant individual constraints involve personal protection equipment (including face masks) that must be worn on duty and during social interactions. Police officers need to develop adaptive solutions to communicate and interact with citizens under these constraints. Variable constraints involve (a) increased anxiety or concerns when dispatching to a call of service due to prior information about the involvement of (suspected) COVID-19 positive individuals and (b) potentially depleted resources due to a high number of calls for service without recovery.

The constraints-led approach allows learners to adopt functional behaviour through cleverly designed and manipulated learning tasks that simulate the demands in the field. Such learning tasks encompass a broad range of training activities ranging from solo activities over one-on-one partner simulations to complex scenarios. Concerning complex scenarios, police officers may be subjected to either unprecedented scenarios, such as the enforcement of restrictions on common behaviours (e.g., controlling quarantine, disbanding of small groups, banning civilians from public spaces), spitting attacks as hazardous behaviour of assailants, and navigating through larger groups (potentially during riots) while maintaining physical distance, or to familiar scenarios, such as domestic violence, identity checks, or vehicle controls which have been impacted by the COVID-19 pandemic and the resulting public

health measures and may as such be adapted by integrating pandemic-specific constraints. As an example of a complex scenario, trainees may respond to a domestic violence call at a 60 square meter apartment involving several individuals. This situation already provides the frame for various possible stressors for police officers: There is a confined space to keep distance and a limited space to interrogate the involved parties separately. Following the constraints-led approach, additional stressors can be embedded to the scenario based on the learner's skill level: Facial masks are worn by all involved persons, leading to a loss of information due to the inability to read facial expressions, or masks are not worn, increasing the perceived risk of infection. The perceived risk of infection can be further increased by providing prior information about an involved person being COVID-19 positive. On top of that, the involved persons might display an unwillingness to comply with social distancing rules, resulting in a high initial potential for aggression (and such for close contact situations).

VR offers a particular opportunity to implement the concept of the constraint-led approach (Giessing, 2021). A major advantage of VR training is the higher control over training procedures (e.g., order of events, level of complexity, risk mitigation) compared to traditional police training (Jaspaert & Vervaeke, 2020; Murtinger et al., 2021). Police trainers can configure scenarios according to the needs of the trainees and training aims. As such, VR training offers a great variability in training scenarios for a range of situations. It allows for the introduction of a wide range of examples and permutations of situation-specific (pandemic-related) conditions, which are often very difficult to include in traditional and/or real-life training due to practical (e.g., budget, logistics) or ethical (e.g., too dangerous for trainees or actors in the scenarios) reasons. Through this variability, trainees are encouraged to explore and train individualized strategies and functional problem solutions to cope with the specific demands (Körner & Staller, 2020a, 2020b).

Besides letting learners explore possible solutions and functional behaviour through representatively designed and constrained learning tasks, police trainers may also proactively provide options for functional behaviour if this is wanted and/or needed by the learners (Körner et al., 2020). These may include verbal communication skills, defence behaviour against spitting attacks and maintaining physical distance throughout the interaction. Besides providing opportunities for learning for the job, police training might also teach skills that allow for *learning on the job*. This refers to coping with and learning from demands in the field without prior acclimatisation to the demands officers are subjected to. The current results suggest that learning emotion regulation strategies might prove especially useful to maintain performance in high-stress situations (Giessing et al., 2021; e.g., mindfulness-based approaches, Giessing et al., 2019; Landman et al., 2016).

Summary and conclusion

Although overall officers seemed to tolerate the stress experienced during the first lockdown of the COVID-19 pandemic relatively well, the large inter-individual variance in strain indicated that female officers, officers with less work experience, officers who feel unprepared or engage in maladaptive emotion regulation are at risk to experience severe pandemic-related work stress. Given the persistence of the pandemic, LEAs are required to implement long-term strategies to better prepare (vulnerable) officers to cope with pandemic-specific work demands. Both our quantitative and qualitative results have highlighted that participants perceived their training in self-protection, target-oriented communication, decision-making, and stress regulation as effective coping resources during the pandemic. To increase the transferability of these skills into the field, police trainers should design training settings that are representative for the pandemic-specific demands in the field by purposefully manipulating individual, environmental and task constraints. Based on the re-analysis of officers' reports about pandemic-related work stressors, we identified a set of such constraints

that can be incorporated in unprecedented or familiar training scenarios, in order to better prepare police officers for the demands that they would encounter during pandemic-related situations. Offering high control over training procedures, VR is a prime tool for frequent and varied scenario-based training to better prepare for pandemic outbreaks and other high-stress situations that do not occur frequently, but that can have disastrous consequences if not dealt with appropriately (e.g., CBRNe-disasters; Murtinger et al., 2021). VR allows for the introduction of a wide range of situation-specific stressors that officers may encounter and should maximally be prepared for, which are often very difficult to include in traditional and/or real-life training due to practical (e.g., budget, logistics) or ethical (e.g., too dangerous for trainees or actors in the scenarios) reasons. demands. The project SHOTPROS is currently working on the development of a VR training solution to facilitate the training of police officers' DMA skills in stressful and/or high-risk situations, such as the COVID-19 pandemic.

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