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

1. Introduction

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.

2. 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.

2.1. Participant

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.

2.2. 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.

2.3. Data collection procedures

2.3.1. 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.

2.3.2. 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*).

2.3.3. 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%.

2.4. Statistical Analyses

2.4.1 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.

2.4.2. 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.

2.4.3. 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.

2.4.4. 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 *perceived 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.

3. Results

3.1. 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).

3.2. 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.

3.3. 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).

3.4. 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.

3.5. Dynamic Relationships

The fitted standard linear regression models did not identify a significant linear time trend in *perceived stress* ($\mathrm{R}^2 = .03$, $\mathrm{p} = .226$), 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).

4. 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.

5. 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.