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Police Realistic Tactical Training Is Not Risk-Free: Stress-Induced Wide-QRS Paroxysmal Tachyarrhythmia in a Healthy Police Officer and Professional Athlete

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Abstract

The reported case, a spin-off of a wider ongoing national study investigating the individual stress reactions of police officers during realistic police tactical training, highlights the eventuality that stress-induced paroxysmal arrhythmias might occur and remain undetected without ECG monitoring as a standard practice. The ECG of a 41-year-old frontline police officer (and professional athlete of the State Police's rugby team) was monitored with a wireless, textile-based, wearable device during stressful scenarios implying the use of force. ECG data were processed with the Kubios software to assess training-induced time-varying changes of heart rate variability parameters and of the parasympathetic, sympathetic, and stress indices. Multiparametric analysis of the heart rate variability quantified remarkable stress-induced increment of vagal withdrawal and of sympathetic dominance, with exceptionally high-stress index and sudden occurrence of a wide-QRS paroxysmal tachyarrhythmia (240 bpm) with concomitant operational failure. Subsequent exhaustive mandatory clinical assessment excluded any structural and arrhythmogenic cardiac abnormality. Although exceptional and to the best of our knowledge so far unique, the recording of a stress-induced paroxysmal wide-QRS arrhythmia occurring during realistic tactical training in a healthy police officer and highly fit athlete is worth to be shared as a caveat about the potential risk if eventually occurring in officers with unknown cardiovascular risk factors (e.g., for ischemic heart disease). Moreover, the demonstration that such a high level of stress may occur even in an experienced, healthy, and highly fit officer altering the physiologic dynamicity of brain–heart interaction with a negative consequence on the operational outcome strongly suggests that individual emotional reactions induced by stressful duty events must be safely experienced and assessed with realistic training, to adopt preventive coping strategies, to improve police officers' efficiency in front of threats, and to lower the risk of inappropriate use of force with dramatic consequences on the street.

Keywords Police tactical training · Stress assessment · Heart rate variability · Autonomic nervous system

Background

It is widely recognized that operational police duties require a multiplicity of professional skills and frequently implies a high level of psychophysiological stress and risks. Moreover, in order to effectively perform high-risk tasks (e.g. crowd/riot control, offenders' containment), officers must be prepared for sudden high-intensity psychologically and physically demanding situations, which enhance the risk of personal injuries and potentially misuse of lethal force (Andersen et al. 2018; Baldwin et al. 2019, 2022; Nieuwenhuys and Oudejans 2010; Nieuwenhuys et al. 2015).

To safely guarantee officer's operational stress management capability enhancement (Staller et al. 2022) and optimize outcomes on the street, it is fundamental to identify objective methods to quantify individual stress response (Fenici and Brisinda 2008; Fenici et al. 2011) aiming to update police education standards based on more advanced and realistic training strategies that take into consideration the interconnections among stress, training, and performance.

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The role of realistic tactical training (RTT) to improve police officers' situational awareness and to reduce anxiety with a lower risk of inappropriate use of force is nowadays unquestionable. However, RTT may not be risk-free itself.

In fact, whereas RTT-induced traumatic injuries partially preventable with adequate trainee's fitness testing, physical training, and appropriate use of protective equipment are extensively investigated (Sawyer et al. 2021; Biggs et al. 2022), acute cardiac complications although potentially lethal (Bozeman 2015) are underestimated.

The unicity of this case, an experienced police officer (PO#1) and fitness-certified athlete of the national Police Rugby Team, highlights the possibility that stress-induced paroxysmal arrhythmias might occur silently during police RTT (and eventually remain undetected until becoming fatal), unless a systematic ECG monitoring of the trainees during RTT is introduced as a standard practice.

In fact, ECG monitoring, now widely available, relatively inexpensive, and easy to wear, has proven useful to assess the level of individual stress reaction induced by RTT. The investigational protocol used to exclude concealed cardiac abnormalities and arrhythmogenic risk in an otherwise healthy athletic police officer is described, which avoided a misleading judgment regarding both the fitness for duty and to continue agonistic sports.

Methods

A 41-year-old frontline police officer (active-duty 21 years), attending a police academy specialization course to become a police instructor for special tactical operations, volunteered to be monitored during a RTT session including two scenarios implying high-risk situation and use of force. He was also a professional player of the national Police Rugby Team, undergoing periodical fitness certification for agonistic activity released by a specialist in sports medicine, according to national guidelines.

Before the beginning of the RTT session, baseline physiological and psychological measurements were collected. Health status was assessed with a clinical interview, complete physical examination, including blood pressure, and rest ECG recordings. PO#1 was medication-free and no-smoker. Caffeine and/or alcoholics were avoided in the 24-h period before the training session.

The psychological assessment included State-Trait Anxiety and Anger, with the STAI Y1-Y2 and STAXI2 (Spielberger 1988; Spielberger 1983), and Zung's self-rating depression scale (SDS) (Zung 1965) questionnaires administrated before the onset of the training session. Subjective stress perception and feelings of fear and/or anger during RTT were rated (scale 0–4) with the perceived stress scale (PSS) questionnaire (Cohen et al. 1983), administered immediately after the end of each tactical scenario.

The Realistic Training Scenario

The purpose of the realistic scenarios (implying car patrolling, radio dispatch, high-speed driving to the target, building search, and confrontation to arrest drug dealers) was to challenge the squad (four officers) involved in typical active duties inducing psychophysiological pressure of a real-life police call (Andersen et al. 2018). According to the investigational protocol, the same scenario was repeated twice to check for reproducibility and learning effect.

The realistic scenarios were designed by professional police instructors to induce high levels of stress and to objectively test skills like the cover of the partner, continuous communication, control and handcuffing of suspects, and appropriate use of non-lethal and lethal force when required as previously reported by other authors (Andersen et al. 2016; Brisinda and Fenici 2019; Nieuwenhuys and Oudejans 2010).

The police officers and the experienced instructors playing the role of criminals carried service firearms modified to allow efficient cycling, and firing of special ammunition ejecting paint bullets, while safely impeding the chambering of live rounds. The reported case was responsible for the squad and acting as the first one to get in contact and interact with aggressive suspects. An overview of the training setup is shown in Fig. 1.

Before the scenarios, a "briefing" informed the officers that they had to behave as during a real police call. At the end of the RTT, a debriefing session revised the events comparing subjective officers' reporting of the events with objective individual operational behavior during the scenarios, recorded by multiple video cameras (located in the patrol car, in the building, and hand-operated).

ECG Data Recording and HRV Analysis

Our standardized protocol, parameters, and metrics for real-time assessment of operational stress during realistic police tactical training were previously detailed (Fenici et al. 2011; Brisinda, Venuti et al. 2015; Brisinda, Fioravanti et al. 2015). The rationale to accept the heart rate variability (HRV) as the proxy to assess brain–heart psychophysiological interactions and to monitor transient psychophysiological reactions to acute stress was provided by Thayer et al. (Thayer and Lane 2000; Thayer et al. (2012).

Two ECG leads (bandwidth 0.05–100 Hz) were digitally recorded (sampling frequency: 250 Hz) with a wireless, textile-based, wearable device with three-axis accelerometer (Nuubo, Spain). Raw ECG data were post-processed and analysed with the Kubios software (version 4.0.1)

Fig. 1 **A** Overview of the training facility and the scenarios setup. **B** Driving to the scene (sample 2). **C** Starting building search (sample 3). **D** PO#1 confronting the suspect (first scenario, sample 4)

(Tarvainen et al. 2021) to calculate heart rate (HR) and HRV parameters in the time domain (TD), in the frequency domain (FD), and with non-linear (NL) methods from ten selected time segments (nine of 120 and one of 11 s), as well as continuously with time-varying algorithms.

Although Kubios provides automatic removal of technical artifacts (muscle or movement noise) and detection of the QRS complex, two cardiologists independently reviewed the recordings to accept or correct the automatic editing and to check for the presence of arrhythmic events.

The time-varying estimate of the parasympathetic (PNS), of the sympathetic (SNS) indices, and of the stress index calculated, according to Baevsky and Chernikova (Baevsky and Chernikova 2017; Tarvainen et al. 2021), provided a quick overview of transient changes of the sympatho-vagal modulation, induced by acute stress. The last Kubios software user guide summarizes and explains all HRV parameters (Tarvainen et al. 2021). The PNS index (integrating mean HR, RMSSD, and the NL Poincare Plot D1 parameter) and SNS index (integrating mean HR, the non-linear Poincare Plot D2 and the stress-index) assess respectively the PNS and SNS tone compared to the resting values of a normal population (Nunan et al. 2010).

Results

The miniaturized wearable device was efficient to obtain continuous ECG recordings of good enough quality for a reliable post-processing and advanced HRV analysis, during the whole monitoring period of more than 2 h.

All basal psychological test scores were within the normal range. The subjective perception of stress during RTT was rated 2 out of 4 in the PSS questionnaire's stress scale, thus moderate-high.

Heart Rate Variability, PNS, SNS, and Stress Indices

An overview of the time-varying analysis of the whole experiment and of some relevant HRV parameters, as graphically summarized by Kubios, is shown in Fig. 2, where the light blue vertical bars on the tachogram (RR time series) indicate the time segments selected (nine of 120 s, one of 11 s).

The values of the most relevant HRV parameters, calculated at each selected interval, are summarized in Table 1.

From the data, it is immediately evident that the ANS modulation of PO#1 was unbalanced toward a net prevalence

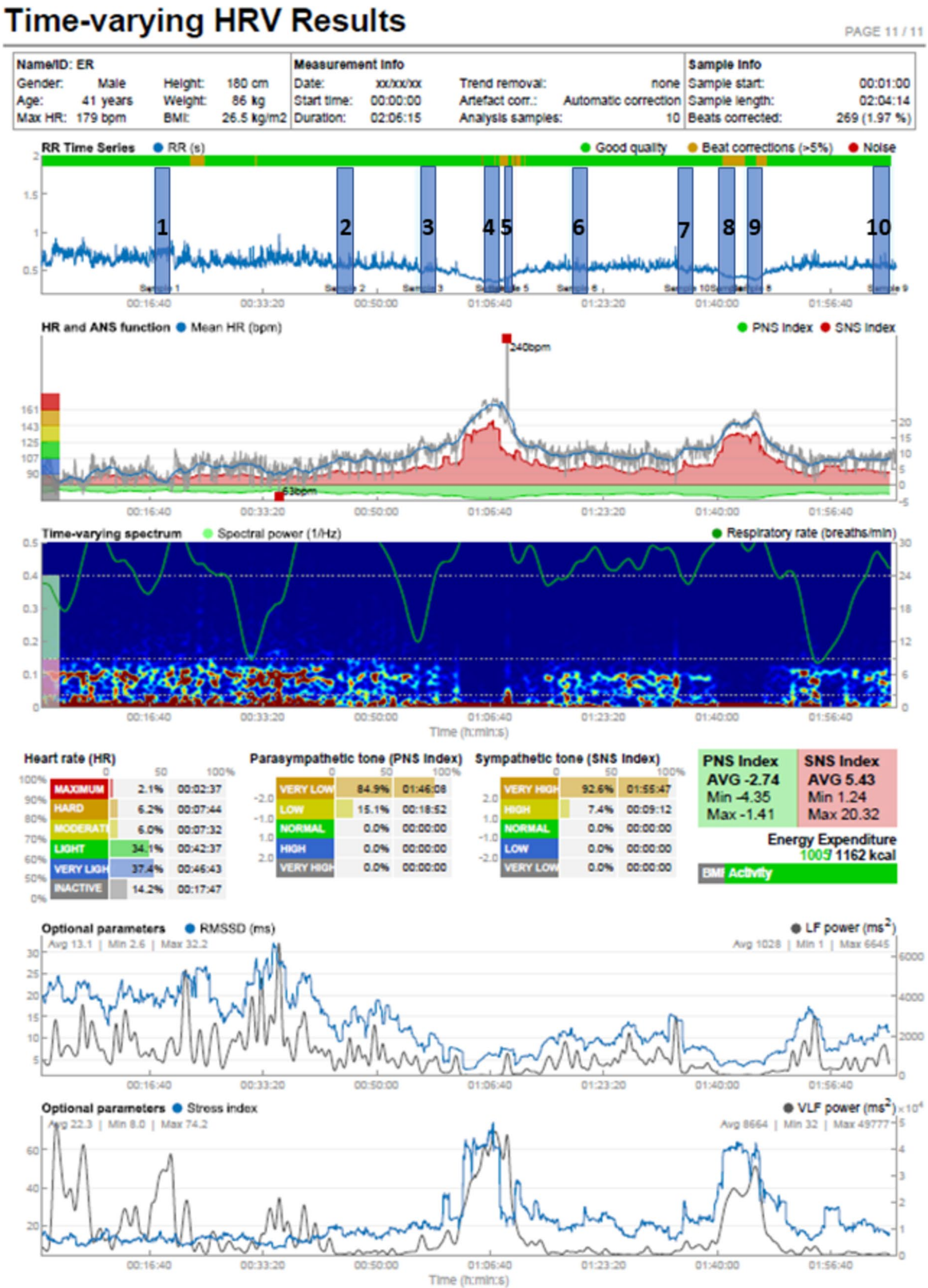

Fig. 2 Example of a standard overview of time-varying HRV analysis of the whole monitoring session, provided by Kubios. The light blue bars on the tachogram (upper strip) indicate the time segments (samples 1 to 10) selected for short-time HRV analysis (parameters are detailed in Table 1)

Table 1 HRV parameters, calculated at each selected time segment (samples 1–10)

		First scenario					Second scenario				
		Baseline	Driving	Entering	Handcuffing	W-QRS-TA	Baseline	Entering	Handcuffing	Checking	Recovery
Overview	PNS index	−1.7	−2.6	−3.2	−4.3	−5.1	−2.9	−3.2	−4.0	−4.1	−2.7
	SNS index	2.1	3.7	5.4	17.9	55.4	5.2	6.9	15.6	13.1	3.9
	Stress index	14.5	14.8	18.8	61.6	225.0	21.0	28.1	61.0	44.3	15.9
TD	Mean RR (ms)	726.1	569.2	510.1	361.5	250.1	538.2	513.2	419.1	400.2	570.0
	SDNN (ms)	43.4	38.3	39.6	12.2	0.4	31.0	26.4	13.1	15.5	41.3
	Mean HR (beats/min)	82.6	105.4	117.6	166.0	239.9	111.5	116.9	143.2	149.9	105.3
	Max HR (beats/min)	98.8	114.2	131.3	173.6	240.0	125.2	130.0	150.3	160.8	117.5
	RMSSD (ms)	18.0	13.3	8.7	6.0	0.38	9.4	7.2	4.5	4.3	13.1
FD (FFT)	VLF (ms^2)	514.2	443.3	1127.8	113.8		379.4	507.3	25.1	88.6	533.0
	LF (ms^2)	768.9	395.8	117.0	0.7		1108.7	129.2	30.1	34.9	1168.1
	HF (ms^2)	99.3	30.2	7.3	0.7		61.1	8.0	2.0	2.1	45.0
	Total power (ms^2)	1382.9	869.4	1252.1	115.3		1549.2	644.6	57.2	125.6	1746.0
	LF/HF ratio	7.7	13.1	16.0	1.0		18.2	16.1	14.9	16.8	26.0
NL	SD1 (ms)	12.73	9.41	6.14	4.24	0.28	6.65	5.10	3.19	3.08	9.29
	SD2 (ms)	60.15	53.44	55.79	16.76	0.27	43.41	37.10	18.20	21.75	57.61
	ApEn	0.81	0.56	0.40	1.01		0.63	0.64	0.81	0.71	0.62
	SampEn	1.16	0.57	0.34	1.21		0.61	0.49	0.79	0.64	0.64
	DF alpha 1	1.65	1.81	1.89	0.89		1.84	1.69	1.30	1.30	1.96
	DF alpha 2	0.66	0.57	0.94	1.18		0.92	0.91	1.01	0.94	0.58
	RP Mean (beats)	11.08	15.30	20.23	39.84		16.50	16.45	23.30	25.28	15.82
	RP Max (beats)	155.00	188.00	225.00	323.00		213.00	224.00	276.00	289.00	200.00
	RESP (Hz)	0.39	0.65	0.21	0.62	0.51	0.44	0.37	0.56	0.47	0.44
	Samples	1	2	3	4	5	6	7	8	9	10

ApEn, approximated entropy; *SampEn*, sample entropy; *DF*, detrended fluctuation analysis; *RP*, recurrence plot analysis; *W-QRS-TA*, wide-QRS tachyarrhythmia; *TD*, time domain; *FD*, frequency domain; *NL*, nonlinear; *RESP*, respiration of SNS already before the beginning of the realistic scenario (sample 1), as demonstrated by a PNS index that significantly decreased (− 1.7 SD) compared to resting normal values and a stress index above 10 (Fig. 3).

Moreover, after the dispatcher call, during high-speed driving to the scene (sample 2), PO#1's HR raised to 114 bpm, with enhanced unbalance of the sympathy-vagal modulation due to further decrease of the vagal tone and increase of the stress index from 14.5 to 18.8. Those changes, considerably significant, were mostly induced by psychological stress, because it occurred in the absence of any other significant physical effort (PO#1 not driving).

While searching the building (sample 3) and approaching an aggressive drug dealer shouting and resisting the arrest, PO#1 had difficulty, despite his physical superiority, to take the suspect to the ground, to control, and to handcuff him (sample 4). His HR reached 174 bpm, with the emergence of isolated supraventricular and ventricular extrasystoles. PNS, SNS, and stress indices (− 4.3, 17.9, and 61.6, respectively) were consistent with remarkable vagal withdrawal and sympathetic dominance (Fig. 3, sample 4). Immediately after, while trying to secure the arrested offender out of the room, the officer was shot by the handcuffed offender with a hidden (and undetected!) handgun. His HR suddenly raised to 240 bpm for the occurrence of an unsustained (12.5 s) wide-QRS paroxysmal tachyarrhythmia (W-QRS-TA) (sample 5—Fig. 3B). During the W-QRS-TA, the PNS, SNS, and stress indices (calculated from an 11-s interval) were out of scale (− 5.14, 55.4, and 225, respectively).

During the recovery period between the two repetitions of the same scenario (sample 6), all indices were consistent with persistent dominance of the sympathetic modulation. When the scenario was repeated for the second time (samples 7–9), a reproducible behavior of the PNS, SNS, and stress indices was observed compared with the first scenario, however, with lower peak HR, without the occurrence of significant arrhythmias (only isolated ventricular extrasystoles) and a with positive operational outcome.

Interestingly, when evaluating the correlation among the PNS, SNS, and stress indices and HRV parameters not used to calculate those indices, but by themselves, sensitive to the effects of acute stress, some unexpected findings were observed. In fact, a time-varying progressive increment of the VLF power (almost overlapping the trend of the stress index) was observed in both scenarios, before its decrement coincident with the maximum HR peak, and was the most

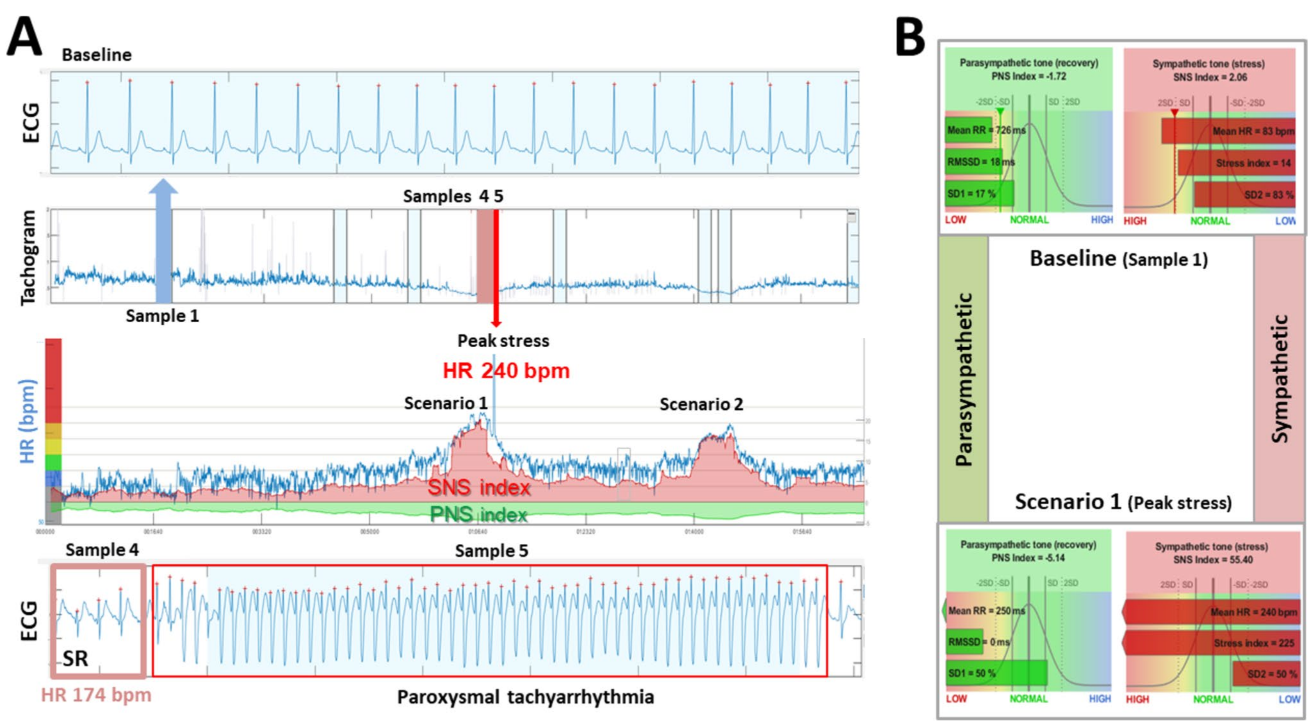

Fig. 3 Detailed analysis of the stress-induced psychophysiological reaction during Scenario 1. **A** Upper strip: baseline ECG in sinus rhythm (sample 1, blue arrow on the tachogram), and peak stress ECG (lowest strip, showing marked sinus tachycardia 174 bpm (sample 4)), followed by sudden onset of the wide-QRS paroxysmal arrhythmia, at 240 bpm (sample 5, thin red arrow on the tachogram). Concomitant time-varying changes of the heart rate (HR), parasympathetic (PNS), and sympathetic (SNS) nervous system indices during the whole session are also shown (strip below the tachogram). **B** Graphic display of PNS (green squares) and SNS (red squares) indices (and of related HRV parameters) at baseline (sample 1), and at peak stress (sample 5), when the PNS index is abnormally low (− 5.14) and the SNS and stress indices are abnormally high (out of scale)

relevant component of the total power, while the LF and HF powers decreased to almost zero during the first scenario (Fig. 2, lowest strip) (Table 1).

Clinical Work-Up to Assess Fitness for Duty and Agonistic Activity After the Arrhythmic Event

Although the wide-QRS morphology of the paroxysmal arrhythmia could be a ventricular tachycardia, its onset modality (two narrow-QRS supraventricular beats of the same cycle length) and the wide-QRS morphology different from that of spontaneous ventricular extrasystoles suggested a supraventricular origin with aberrant conduction. However, although PO#1 was completely asymptomatic during the event, the unexpected occurrence and ECG-documented W-QRS-TA during the RTT session created a serious problem from the point of view of the medical evaluation of the physical fitness as required by our national law for both the frontline police duty and for the agonistic sports activity. Thus, an exhaustive clinical work-up was needed to exclude any structural heart disease and/or electrophysiological vulnerability to life-threatening arrhythmias.

Luckily, besides the negative clinical history, the absence of structural abnormalities and excellent physical conditioning was confirmed by echocardiography at rest and during effort. The 12-lead ECG was normal and without the occurrence of any arrhythmia during and after a strenuous effort test, carried out until muscular exhaustion. No arrhythmia occurred during prolonged (1 week) ECG Holter monitoring, including several physical training sessions.

In addition, a transoesophageal electrophysiological study (TEPS) was carried out, at rest and during maximal effort, to evaluate the inducibility of the arrhythmia observed during the RTT, its electrophysiological mechanism, and eventual reproducibility of the wide-QRS morphology.

The TEPS documented physiologic dual Atrio-Ventricular Nodal (AVN) conduction pattern, without inducibility of sustained arrhythmias at rest and under effort, with the S1-S2-S3 paired protocol until the shortest cycle of drive pacing, which reproduced only two AVN eco-beats, with transient Right Bundle Branch Block (RBBB) consistent with the wide-QRS observed during the realistic scenario. With aggressive burst pacing, a short run of unsustained narrow-QRS AVN re-entry tachycardia (AVNRT) was inducible only at the peak of effort test at 84% Tmx HR (i.e., during 3′ at a load of 200 watts) that spontaneously reverted to sinus rhythm. All the findings of the TEPS were in good agreement with the interpretation of the spontaneous arrhythmia being of supraventricular origin with transient intraventricular conduction aberrancy. The absence of inducibility with very aggressive atrial burst pacing excluded the alternative diagnosis of atypical atrial flutter.

PO#1 was considered fit for duty and for agonistic sports activity and was thereafter followed up (at today for 7 years) with periodical clinical visits including effort ECG, 24-h ECG Holter monitoring (always including at least one training session), and echocardiography, confirming full healthy conditions and absence of arrhythmias. In the last 2 years, PO#1 was assigned to a highly demanding police special squad for riot and crowd control, with optimal performance. After leaving the rugby competitions at the age of 45, he is still performing semi-agonistic athletics (half marathon) training, with good age-related performance.

Discussion

Operational law enforcement duties imply a high level of psychophysiological stress, especially in conditions where the amount of individual control may be overwhelmed by the sudden unexpected use of violence by the offenders, which, anyhow, police officers are required to be able to contain and manage as safely as possible, with graded and appropriate use of force (Vickers and Lewinski 2012; Andersen et al. 2018).

However, as pointed out in a recent Urgent Issue Paper, promoted by the British Psychological Society (Bennell et al. 2021), the matter of appropriateness in the police use of force is very complex and yet far from being univocally solved, despite research related to police use of force has grown considerably.

In fact, also in that paper, suggestions given separately by police practitioners and academic researchers, addressing the problem from different points of view, were somehow diverging. However, all experts agree that police officers must receive RTT, to learn modulating their physiologic response to operational stress (Andersen et al. 2016; Andersen et al. 2018) by implementing, in police as in military training, real-world stressors in the practice of required skills, to safely inoculate positive stress, to favour the adaptation of the individual skills to the tactical needs (Cañal-Bruland 2010), and to reduce the negative impact that stress can have on officers' decision-making, tactical performance, and event memory (Bennell et al. 2021).

HRV Markers of Acute Threat-Induced Psychological Stress

A problem still unsolved is how to measure objectively the amount of individual reaction to high-level of stress induced by highly demand and potentially life-threatening street encounters. It is clear that the first necessary step is to ideally provide officers with wearable non-intrusive monitoring sensors alerting them in real time to recognize the symptoms associated with ANS imbalance and to teach them during RTT how to regain a better parasympathetic control through simple techniques like the "reset (or tactical) breath" (Andersen et al. 2018; Bennell et al. 2021).

Thanks to technological advances, continuous monitoring of HR is nowadays possible with relatively inexpensive wearable devices, and several of them are also validated as CE-marked medical devices by comparison with ECG Holter monitoring (Hinde et al. 2021). However, previous research has provided evidence that the absolute value of maximum peak HR may be uncorrelated to operational efficacy and cannot be assumed as a univocal index to quantify individual stress (Meyerhoff et al. 2004; Fenici et al. 2011). Therefore, following the seminal work of the pioneers of its application in psychophysiology (McCraty and Tomasino 1999; Kreibig 2010; McCraty and Atkinson 2012; and referenced therein), HRV analysis has been proposed as a more advanced method to study also cardiac autonomic reactions induced by acute survival stress in police officers during RTT (Fenici et al. 2011). Since then, multiple studies have used HRV analysis to measure the stress induced by tactical manoeuvres (McCraty and Atkinson 2012; Brisinda, Venuti et al. 2015; Brisinda, Fioravanti et al. 2015; Head et al. 2017; Baldwin et al. 2019, 2022; Giessing et al. 2019; Gancitano et al. 2021).

As pointed out recently (Laborde 2017), the application of HRV in psychophysiology should focus on the fact that the HRV is mostly representative of the vagal tone that should be always quantified at least with the RMSSD, pNN50, and HF power (absolute value) parameters (Malik 1996; Thayer and Lane 2000; Porges 2009; Thayer et al. 2012).

In this case report, the PNS and SNS indices were also available and demonstrate that, despite PO#1's normal psychological profile and optimal physical fitness for sports activity, the baseline ANS modulation was unbalanced toward a net prevalence of SNS already before the beginning of the RTT session (sample 1) (Fig. 3A). The baseline PNS index was already low (i.e., almost − 2 SD, compared with resting normal values) and decreased markedly under the stress induced by the first scenario, reaching − 4 SD when PO#1 had difficulty handcuffing the suspect. Coherently, also, the HF power was low and decreased to almost zero (Table 1, sample 4).

According to the Neurovisceral Integration Model (Thayer and Lane 2000), this dysfunctional loss of parasympathetic modulation has locked the officer's "brain–heart-body system" capability to be flexible, leading to insufficient rational control of the scene and consequent loss of attention in searching the suspect for possibly hidden firearms, with unavoidable dramatic failure of his operational performance. Moreover, the PNS index remained very low along the whole interval between the first and the second scenario, indicating a lack of recovery.

The calculation of the time-varying SNS and stress indices was useful to provide a quick graphical overview of acute and persistent stress-induced prevalence of the sympathetic drive during RTT (Fig. 3). Interestingly, also the time-varying increment of the VLF power observed during both RTT scenarios (Fig. 2, lowest strip), mimicking the trend of the HR and of the stress index, seems in agreement with the interpretation of VLF power as a marker of stress-induced enhancement of intrinsic cardiac sympathetic activity suggested by experimental research in the dog's heart (Armour 2008; Shaffer et al. 2014) and by its correlation with physical activity (Bernardi et al. 1996; Lu et al. 2016), although the VLF spectral component is usually considered expression of slower physiological mechanisms (Taylor et al. 1998; Lampert et al. 2008; Shaffer et al. 2014; Shaffer and Ginsberg 2017), sympatho-vagal balance, vagal tone, and its decrement during mental stress (Usui and Nishida 2017).

However, the calculation from selected time segments has shown that also in this case, after the increase observed at a medium level of stress (samples 3 and 7), the VLF power markedly decreased (below the baseline value) in concomitance with maximum stress (samples 4, 8, and 9). This observation reinforces the fact that HR oscillations of a healthy heart are complex and nonlinear and that, while increased VLF power in 24 h HRV assessment is consistent with health status, the same change during short-term assessment may be an indicator of excessive effort (Shaffer and Ginsberg 2017). At the moment, it is still difficult to differentiate at what extent the effect of the psychological and physical stress may interact (Brindle et al. 2014) and affect individual performance during RTT, although a good discrimination accuracy obtained with non-linear HRV parameters has been reported (Brisinda, Fioravanti et al. 2015).

The significant progressive decrement of the LF power (especially during the first scenario), in evident contrast with the concomitant marked increase of the independently calculated SNS index, may reinforce the debate about the interpretation of the LF spectral component as an index of sympathetic activity (Goldstein et al. 2011).

Time-varying changes of non-linear parameters were only partially consistent with the increment of the SNS index. In fact, whereas as expected, the Recurrence Plot parameters (RPA Mean and Max) progressively increased with stress, the Entropy parameters (ApEn and SampEn), progressively decreased at medium stress (samples 3 and 7), and showed a paradoxical although only mild increment at the peak stress (samples 4 and 8).

The HRV analysis during the ultra-short interval (11 s) of the W-QRS-TA (sample 5, Fig. 3B) provided a reasonable estimation of enhanced PNS withdrawal (PNS index − 5, 14) (Table 1, sample 5) and the overall results were consistent with a "crescendo" effect of stress induced by the situational difficulty, ending in operational failure. However, the extremely high HR and concomitant null HRV might have affected, although mathematically correct, the calculation of the SNS and stress indices, which were extremely high. It should be noted that the HR of the W-QRS-TA was 240 bpm under RTT psychological stress despite minimal physical effort, whereas the HR of the AVNRT induced clinically with TEPS did not exceed 200 bpm during maximum effort.

Interestingly, at the repetition of the scenario, despite the high-stress index at baseline (sample 6) and its further rise (samples 8 and 9), the increment of the SNS index and of the HR was lower compared with the first one, indicating that the PO#1 had a better (learning-induced) emotional and situational control. In fact, the operational outcome was positive.

Tactical Training and Arrhythmias

The reported case confirms that RTT should be widely applied, but with adequate monitoring of individual psychophysiological response at least as shown here. In fact, without the ECG monitoring, the unexpected exceptional individual stress reaction of this experienced frontline police officer would have not been proven as the most reasonable cause of the operational failure. Even more importantly, since the arrhythmic event was asymptomatic, it would have remained undetected. Luckily, being the officer healthy and an optimally fitting athlete, the arrhythmia was self-limiting within few seconds without any consequence. However, the same event could have had dramatic consequences if the officer involved was for instance affected by a silent coronary artery disease as the case occurred in North Carolina (Bozeman 2015).

The detection of the spontaneous unsustained wide-QRS arrhythmia during RTT placed a serious unpredicted problem of mechanistic and of clinical interpretation of such finding, because in some nations like ours, fitness evaluation for law enforcement and military duty, as well as for agonistic sports activity, is mandatory and would have implied a negative judgment and suspension from active duty until the given demonstration that there was no structural or electrophysiological cardiac pro-arrhythmic abnormality.

Luckily, the arrhythmogenic mechanism in the reported case was somehow "physiologic" and could be found in the correlation between the exceptional level of stress-induced sympathetic activation, cardiac afferent signalling to the brain, and efferent "central command" processes controlling the cardiac function (Thayer and Lane 2000; Porges 2009, 2022; Shaffer et al. 2014) (in this case, a critical autonomic modulation of dual AVN conduction properties, with the casual triggering of an unsustained AV-nodal tachycardia, by a couple of supraventricular extrasystoles).

Limitations

Although exceptional and, to the best of our knowledge, so far unique finding occurred during RTT, it is obvious that the results of a single case cannot be extrapolated to a general police or military population. However, we believe that it is worth to be shared with other colleagues involved in military medicine, as caveat about the potential risk of unexpected arrhythmias as the one described if occurring in an officer with unknown coronary artery disease (Bozeman, 2015).

From our side, the reported findings have triggered our attention to revise our data (so far acquired to answer confidentially to the volunteers' request to know their own cardiac performance during RTT) and to design a more structured prospective study checking systematically for the eventual occurrence of arrhythmias to attempt a better understanding of the mechanistic correlation with the level of individual stress quantified with advanced HRV analysis.

Conclusions

In conclusion, the frontline police officer is "de facto" required to be a top-ranking performer, with multiple skills and high psychophysiological resilience.

As in sports medicine, we need to learn from research. In fact, this case report demonstrates that even a highly physically fit athlete, having a negative stress-induced psychophysiological reaction during a dangerous intervention, although surviving a high-rate paroxysmal arrhythmia, can lose situational control, act wrongly, and get killed. We strongly believe that such kind of research should be improved and applied on a larger scale to gather more and more new knowledge about how acute stress during police critical incidents may affect the appropriate operational officer's behavior, leading to avoidable death of police officers and/or inappropriate use of force, with dramatic outcome on the street.

To improve resilience, not only individual self-regulation strategies that promote recovery and protect against additional negative effects of work-related fatigue and sleep deprivation but also institutional strategies for stress assistance should be seriously implemented (van Peer 2019). In fact, although PO#1 was a highly fit agonistic athlete practicing a sport requiring strength, courage, strategy and tactical skills, and heavy physical confrontation, this personal strategy was evidently not enough to help manage the different levels of psychological stress induced by a potentially life-threatening police confrontation.

Practical Implications

- Police tactical training must be as much realistic as possible, considering that the physiologic dynamicity of brain-heart interaction may be altered by the high level of stress induced by life-threatening events and that such a hard emotional experience must safely occur during training and not dangerously on the street.
- Stress-induced arrhythmias can occur during RTT even in healthy police officers. Thus, ECG monitoring is recommended to improve training safety and to better assess individual fitness evaluation.
- Since unknown or underestimated cardiovascular risk factors might induce life-threatening arrhythmias and even SD in frontline police officers under RTT stress (Bozeman 2015), they should be periodically checked for fitness.

- **All POs should be trained in CPR and to the use of AED (which must be available at the training facility), to help their peers in an emergency (Bozeman 2015).Funding** Open access funding provided by Università Cattolica del Sacro Cuore within the CRUI-CARE Agreement.

Declarations

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards and were conducted as authorized by the local police institutional authority. This article does not contain any studies with animals performed by any of the authors.

Informed Consent Informed consent was obtained from all individual participants included in the study. The person described in the study gave written informed consent for the anonymized use of his data for scientific teaching and publication.

Conflict of Interest The authors declare no conflict of interests.

References

Andersen JP et al (2016) Highly realistic scenario-based training simulates the psychophysiology of real-world use of force encounters: implications for improved police officer performance. Journal of Law Enforcement 5(4):1–13

Andersen JP et al (2018) Reducing lethal force errors by modulating police physiology. J Occup Environ Med 60(10):867–874. https://doi.org/10.1097/JOM.0000000000001401

Armour JA (2008) Potential clinical relevance of the "little brain" on the mammalian heart. Exp Physiol 93(2):165–176. https://doi.org/10.1113/expphysiol.2007.041178

Baevsky RM, Chernikova AG (2017) Heart rate variability analysis: physiological foundations and main methods. Cardiometry 10:66–76. https://doi.org/10.12710/cardiometry.2017.10.6676

Baldwin S et al (2019) Stress-activity mapping: physiological responses during general duty police encounters. Front Psychol 10(October):1–17. https://doi.org/10.3389/fpsyg.2019.02216

Baldwin S et al (2022) A reasonable officer: examining the relationships among stress, training, and performance in a highly realistic lethal force scenario. Front Psychol 12(January). https://doi.org/10.3389/fpsyg.2021.759132

Bennell C et al (2021) Advancing police use of force research and practice: urgent issues and prospects. Leg Criminol Psychol 26(2):121–144. https://doi.org/10.1111/lcrp.12191

Bernardi L et al (1996) Physical activity influences heart rate variability and very-low-frequency components in Holter electrocardiograms. Cardiovasc Res 32(2):234–237. https://doi.org/10.1016/0008-6363(96)00081-8

Biggs AT, Doubrava MR, Littlejohn LF (2022) Head wounds received during force-on-force training with non-lethal ammunition. Mil Med 187(5–6):e787–e791. https://doi.org/10.1093/milmed/usab054

Bozeman WP (2015) Officer safety corner: another save: sudden cardiac arrest during bomb squad training. The Police Chief LXXXII(7):12–13. Available at:https://www.policechiefmagazine.org/wp-content/uploads/IAC-306-Police-Chief-July-2015-web.pdf

Brindle RC et al (2014) A tale of two mechanisms: a meta-analytic approach toward understanding the autonomic basis of cardiovascular reactivity to acute psychological stress. Psychophysiology 51(10):964–976. https://doi.org/10.1111/psyp.12248

Brisinda D, Venuti A et al (2015) Real-time imaging of stress-induced cardiac autonomic adaptation during realistic force-on-force police scenarios. J Police Crim Psychol 30(2):71–86. https://doi.org/10.1007/s11896-014-9142-5

Brisinda D, Fenici R (2019) Evaluation of acute psycho-physiological reaction to law enforcement operational stress and tactical driving. 20 years of prospective Italian research. Eur Heart J 40(1):ehz745.0746. https://doi.org/10.1093/eurheartj/ehz745.0746

Brisinda D, Fioravanti F et al (2015) Psychophysiological assessment of acute stress induced by high-pressure law-enforcement driving: a pilot study. 2(3):36–50. https://doi.org/10.12966/psbr.06.03.2015

Cañal-Bruland R, Pijpers JR, Oudejans RRD (2010) The influence of anxiety on action-specific perception. Anxiety Stress Coping 23(November 2012):353–361. https://doi.org/10.1080/10615800903447588

Cohen S, Kamarck T, Mermelstein R (1983) A global measure of perceived stress. J Health Soc Behav 24(4):385–396. Available at:http://www.jstor.org/stable/2136404

Fenici R, Brisinda D (2008) Stress-induced changes of heart-rate variability in police officers during operational training for demanding tactical tasks. Eur Heart J 29(1):750. https://doi.org/10.1093/eurheartj/ehn377

Fenici R, Brisinda D, Sorbo AR (2011) Methods for real-time assessment of operational stress during realistic police tactical training. Handbook Police Psychol 295–319. Available at:https://login.ezproxy.net.ucf.edu/login?auth=shibb&url=http://search.ebscohost.com/login.aspx?direct=true&db=psyh&AN=2011-08971-014&site=ehost-live

Gancitano G et al (2021) HRV in active-duty special forces and public order military personnel. Sustainability (switzerland) 13(7):1–15. https://doi.org/10.3390/su13073867

Giessing L et al (2019) Effects of coping-related traits and psychophysiological stress responses on police recruits' shooting behavior in reality-based scenarios. Front Psychol 10(JULY). https://doi.org/10.3389/fpsyg.2019.01523\

Goldstein DS et al (2011) Low-frequency power of heart rate variability is not a measure of cardiac sympathetic tone but may be a measure of modulation of cardiac autonomic outflows by baroreflexes. Exp Physiol 96(12):1255–1261. https://doi.org/10.1113/expphysiol.2010.056259

Head J et al (2017) Prior mental fatigue impairs marksmanship decision performance. Front Physiol 8(SEP):1–9. https://doi.org/10.3389/fphys.2017.00680

Hinde K, White G, Armstrong N (2021) Wearable devices suitable for monitoring twenty-four-hour heart rate variability in military populations. Sensors (switzerland) 21(4):1–20. https://doi.org/10.3390/s21041061

Kreibig SD (2010) Autonomic nervous system activity in emotion: a review. Biol Psychol 84(3):394–421

Laborde S, Mosley E and Thayer JF (2017) Heart rate variability and cardiac vagal tone in psychophysiological research - recommendations for experiment planning, data analysis, and data reporting. Front Psychol 8(FEB). https://doi.org/10.3389/fpsyg.2017.00213

Lampert R et al (2008) Decreased heart rate variability is associated with higher levels of inflammation in middle-aged men. Am Heart J 156(4):759.e1-759.e7. https://doi.org/10.1016/j.ahj.2008.07.009

Lu D-Y et al (2016) Heart rate variability is associated with exercise capacity in patients with cardiac syndrome X. PLoS One 11(1):e0144935. https://doi.org/10.1371/journal.pone.0144935

Malik M (1996) Guidelines heart rate variability. Eur Heart J 17:354–381. https://doi.org/10.1161/01.CIR.93.5.1043

McCraty R, Tomasino D (1999) Impact of the HeartMath self-management skills program physiological and psychological stress in police officers. (99):21

McCraty R, Atkinson M (2012) Resilience training program reduces physiological and psychological stress in police officers. Global Advances in Health and Medicine 1(5):44–66. https://doi.org/10.7453/gahmj.2012.1.5.013

Meyerhoff JL et al (2004) Evaluating performance of law enforcement personnel during a stressful training scenario. Ann N Y Acad Sci 1032:250–253. https://doi.org/10.1196/annals.1314.031

Nieuwenhuys A, Oudejans RRD (2010) Effects of anxiety on handgun shooting behavior of police officers: a pilot study. Anxiety Stress Coping 23(January 2015):225–233. https://doi.org/10.1080/10615800902977494

Nieuwenhuys A, Savelsbergh GJP, Oudejans RRD (2015) Persistence of threat-induced errors in police officers' shooting decisions. Appl Ergon 48:263–272. https://doi.org/10.1016/j.apergo.2014.12.006

Nunan D, Sandercock GRH, Brodie DA (2010) A quantitative systematic review of normal values for short-term heart rate variability in healthy adults. Pace - Pacing and Clinical Electrophysiology 33(11):1407–1417. https://doi.org/10.1111/j.1540-8159.2010.02841.x

Porges SW (2009) The polyvagal theory: new insights into adaptive reactions of the autonomic nervous system. Cleve Clin J Med 76(Suppl 2):s86–s90. https://doi.org/10.3949/ccjm.76.s2.17

Porges SW (2022) Polyvagal theory: a science of safety. Front Integr Neurosci 16(May):1–15. https://doi.org/10.3389/fnint.2022.871227

Sawyer S et al (2021) Profiling the injuries sustained by police trainees undergoing initial training: a retrospective cohort study. Int J Environ Res Public Health 18(14). https://doi.org/10.3390/ijerph18147335

Shaffer F, Ginsberg JP (2017) An overview of heart rate variability metrics and norms. Front Public Health 5(September):1–17. https://doi.org/10.3389/fpubh.2017.00258

Shaffer F, McCraty R, Zerr CL (2014) A healthy heart is not a metronome: an integrative review of the heart's anatomy and heart rate variability. Front Psychol 5(September):1040. https://doi.org/10.3389/fpsyg.2014.01040

Spielberger CD et al (1983) Manual for the state-trait anxiety inventory. Consult Psychol, Palo Alto, CA

Spielberger CD (1988) Manual for the State-Trait Anger Expression Inventory (STAXI). Psychological Assessment Resources, Odessa, FL

Staller MS et al (2022) Editorial: Police education and training revisited: drawbacks and advances. Front Psychol. https://doi.org/10.3389/fpsyg.2022.1045924

Tarvainen MP et al (2021) Kubios HRV Software USER'S GUIDE. November 3, 2021:4–39. Available at:https://www.kubios.com/downloads/Kubios_HRV_Users_Guide.pdf

Taylor JA et al (1998) Mechanisms underlying very-low-frequency RR-interval oscillations in humans. Circulation 98(6):547–555. https://doi.org/10.1161/01.CIR.98.6.547

Thayer JF, Lane RD (2000) A model of neurovisceral integration in emotion regulation and dysregulation. J Affect Disord 61(3):201–216. https://doi.org/10.1016/S0165-0327(00)00338-4

Thayer JF et al (2012) A meta-analysis of heart rate variability and neuroimaging studies: implications for heart rate variability as a marker of stress and health. Neurosci Biobehav Rev 36(2):747–756. https://doi.org/10.1016/j.neubiorev.2011.11.009

Usui H, Nishida Y (2017) The very low-frequency band of heart rate variability represents the slow recovery component after a mental stress task. pp 1–9.https://doi.org/10.5061/dryad.7pn71.Funding

van Peer JM, Gladwin TE and Nieuwenhuys A (2019) Effects of threat and sleep deprivation on action tendencies and response inhibition. Emotion 19(8):1425–1436

Vickers JN, Lewinski W (2012) Performing under pressure: gaze control, decision making and shooting performance of elite and rookie police officers. Hum Mov Sci 31(1):101–117. https://doi.org/10.1016/j.humov.2011.04.004

Zung WK (1965) A self-rating depression scale. Arch Gen Psychiatry 12(1):63–70. Available at:https://doi.org/10.1001/archpsyc.1965.01720310065008