Investigating motivational aspects and psychobiological stress responses in high-risk sports combining Virtual Reality to a wing-suit flight simulator: study protocol of the project *StressVR*

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Abstract:

Over the last decades, the prevalence of high-risk sports activities including skydiving, base-jumping, and wingsuit flying has co-developed with a modern globalized lifestyle. The practice of such extreme sports with a risk-taking and even life-threatening character shows continuously increasing popularity and participation rates have grown exponentially. Interestingly, the precise motivational aspects of high-risk sports and their psychobiological underpinnings have been rather hardly characterized. This limited knowledge is attributable to the fact that the possibility to investigate high-risk sports in a laboratory setting was relatively limited. The central methodological aim of the presented project *StressVR* is to use groundbreaking new technology in high-risk sports research by implementing Virtual Reality (VR) technology into a psychobiological research environment. Using a first-of-its-kind VR wingsuit-flight simulator, *StressVR* will identify and characterize the kinetics of psychobiological reactions in the context of high-risk sport behavior, also considering critical and traumatic life events, personality traits, attachment representations as well as biomolecular readout variables including cortisol, beta-endorphin, *alpha-amylase* activity, and pH in saliva. Additionally, peripheral stress markers including heart rate, respiration rate, and skin conductance will be assessed during the VR experiment. The results of *StressVR* will not only help to improve the current understanding of why individuals do high-risk sports: This could also mean that risk sports athletes do not act “headlessly” and “carelessly” but do follow their metabolic needs as a mechanism of emotion regulation. Here, we summarize the concepts of *StressVR* and provide the study protocol to address the aimed scientific questions.

Keywords: Stress, Physiology, Personality traits, High-risk sports, Attachment representation, Virtual Reality, Wingsuit-flight simulator; Salivary biomarkers

1. Introduction

1.1 High-risk sports and modern lifestyle

The prevalence of risk-sports activities including skydiving, base-jumping, and wingsuit flying has co-developed with a modern globalized lifestyle. The practice of extreme sports with a risk-taking or even life-threatening character is of increasing popularity and participation rates have grown exponentially¹. Although extreme sports are associated with high mortality risk, they have become socially acceptable and even gained commercial interests. According to Buckley², activities on an extreme level require the continuous application of skills at the highest level and under high concentration to avoid harmful or even life-threatening consequences. Nevertheless, statistics demonstrate a relatively high percentage of accidents with severe and even fatal consequences³. The precise motivational reasons for high-risk sports and their psychobiological underpinnings have been rather hardly characterized, also due to limited laboratory settings to simulate and investigate such activities. As a consequence, new interdisciplinary research approaches are needed for improving our current understanding of the motivational aspects of high-risk sports participation.

1.2 Motivational aspects of high-risk sports: Findings from psychosocial and sociological research

First reported psychosocial and sociological frameworks provided access to initial insights into this field of science^{1,4-6}. According to Knobloch⁷, participation in high-risk sports underlines the absolute trust in the person's competence in action performance, self-control, and risk management. Consequently, higher risks are more likely to be taken if confidence in one's potential outweighs the risk⁸. In this context, personality traits might be one "missing scientific part of the puzzle". This is of special interest as psychoneuroimmunological research provided evidence for an association between personality traits, immunological reactivity, and physiological stress responses^{9,10}. In general, stressful situations trigger the body to react with physiological changes for the recovery of homeostasis¹¹, which represents the body's physiological state of equilibrium. The underlying core concept is represented by the "fight-or-flight" mechanism first described by Cannon¹². The underlying physiological stress responses can be investigated on different biological levels. For example, cardiovascular reactivity can be observed with alterations in heart-rate variability (HRV) and changes in respiration rate (RR), while endocrine stress responses are mainly mediated via the hypothalamic-pituitary-adrenocortical (HPA) and the sympatho-adrenomedullary (SAM) axis. HPA and SAM reactivity are associated with changes in the steroid hormone cortisol. One of the physiological

effects of cortisol release is the increased availability of energy in terms of glucose from the liver into peripheral blood¹³. Besides cortisol, altered activity patterns were reported for *alpha-amylase* under conditions of psychological stress. *Alpha-amylase* is a digestive enzyme essential for the degradation of amylose to provide disaccharides and monosaccharides for glycolysis and biochemical energy production¹⁴. Salivary *alpha-amylase* (sAA) provides an index of arousal of the sympathetic corticotropin-releasing hormone (CRH) and adrenocorticotrophic hormone (ACTH). A relatively new group of biomarkers used in human stress research includes endorphins. Endorphins are endogenous opioid peptides, which are synthesized in the pituitary gland and the hypothalamus¹⁵. Endorphins, cleavage products of three precursor proteins, initiate various physiological processes in the body. So far, their main identified function is to inhibit the communication of pain sensation^{16,17}. Interestingly, endorphins can also induce mental states e.g. of euphoria, which is a robust observation in athletes following high-risk sports activities¹⁸. Beta-endorphin (BE), a prominent member of the endorphin family, has been investigated for its role in pain reduction¹⁷. Changes in BE during a stressful situation were first demonstrated by Sheps and colleagues¹⁹. They found that psychological stress alters plasma levels of opioid peptides, showing an increasing effect of stress on beta-endorphin. BE can be measured in various body fluids, which was recently extended to saliva assessment in an ambulatory setting in a cohort of individuals conducting non-suicidal self-injury (Karabatsiakos and Stoerkel et al., Neuropsychopharmacology, in press)²⁰. From a methodological point of view, the activity of enzymes is influenced by physiology as every protein shows a *pH* optimum for maximum performance. The *pH* value expresses the acidity or alkalinity of a water-based solution and is defined as the decimal logarithm of the reciprocal of the hydrogen ion activity. The *pH* of saliva is regulated by the parasympathetic and sympathetic nervous system and is also considered a biomarker of psychological and biological stress. Cohen and colleagues²¹ tested students under examination stress before (*t*₁), after (*t*₂) and three months after the exam period (*t*₃) and found an increase in *pH* (more alkaline) from *t*₁ to *t*₃, with salivary *pH* being a strong predictor of exam performance. Stress-associated changes in salivary *pH* might therefore contribute to reported differences in *alpha-amylase* activity under conditions of stress, an underestimated and rather neglected concept of enzyme physiology in stress research. In the following, we will introduce and summarize the current concepts and perspectives on high-risk sports and psychobiological stress responses to provide a rationale for the research questions addressed in the project *StressVR*.

1.3 Adult attachment representation and high-risk sports

To extend the understanding of inter-individual differences in psychobiological stress responses it is important to investigate attachment representations (AR) that are shaped across childhood (for an introduction see^{22,23}). The following four classification types are used to discriminate between different AR: “Secure”, “insecure-avoidant”, “insecure-ambivalent”, and “disorganized/disoriented”. Additionally to these core classifications, disorders of attachment are known in clinical psychology, which are also characterized by differences in psychobiological stress vulnerability and alterations in stress responses^{24,25}.

The *Adult Attachment Projective Picture System* (AAP) by George and colleagues^{23,26} is one of only a few internationally accepted instruments available to assess AR in adolescents and adults in clinical populations and control cohorts^{27–38}. These studies demonstrated the high potential of the AAP as a valid attachment measure to identify the individuals’ attachment-related risk and protective factors in association with psychopathological dimensions, stress response, and differential personalized resources. In the field of experimental research on high-risk sports, Nuderscher and Buchheim⁵ already discussed the AAP as a resource-oriented attachment instrument that could provide further insights into the individual’s risk management by associating AR with risk-taking behavior. Consequently, the AAP will be applied in *StressVR*.

1.4 Psychobiological stress research in high-risk sports

Considering high-risk sports as a stressful experience, the body’s stress response not only comprises neurocognitive but also physiological processes. These do not include single responses but rather orchestrate inter-related body systems including the central and the peripheral nervous system, the endocrine system, and the immune system. Biological markers to investigate physiological reactions for compensating stress-mediated challenges include variables that can be addressed in biofluids either invasively (e.g. venous blood, serum, plasma) or non-invasively collected (e.g. saliva, sweat, urine). For example, Nater and colleagues applied psychological stress protocols that demonstrated that salivary *alpha-amylase* (sAA) is very sensitive to stress-related physiological changes³⁹. They showed an increase in the concentration and output of sAA during the stress state, while the salivary flow rate was not affected. However, another physiological marker that is influenced by both physical and psychological stress is the *pH* of body fluids. According to the laws of physiology, the activity of all enzymes is influenced by temperature and *pH*. The physiological consequences of psychobiological stress include a lowering of the *pH* value (more acidic), which also affects the *alpha-amylase* milieu in saliva. Therefore, the *pH* value is an important indicator to improve

the comparability of sAA values between different conditions. In *StressVR* we will co-assess *alpha-amylase* activity and pH in saliva and their kinetics related to a VR wing-suit flight to address the questions of whether salivary *alpha-amylase* changes independently from alterations in saliva pH, which is a hardly addressed aspect in psychophysiological stress research.

1.5 Towards new horizons in psychobiological research on high-risk sports: The Virtual Reality wing-suit flight simulator

A high-risk, non-commercial and privately recorded wingsuit flight was provided by professional wingsuit pilots in Chamonix, France. The recording was digitalized and implemented into VR using a commercially available, professional VR headset (HTC Vive Pro) connected to a Windows-operated personal computer in the laboratories of the Department of Clinical Psychology II at the University of Innsbruck.

The Virtual Reality (VR) technology implemented into the project is applied to enable participants to intensify their perception and to stimulate virtually experienced stress into a physiological stress response. The biological readout variables selected (cortisol, beta-endorphin, *alpha-amylase*, pH), assessed at four measurement time points (t_0 - t_3) with saliva samples during the VR experience, will allow identifying differences in the physiological stress response. Using a self-designed and self-produced electromechanical prototype of a wing-suit flight simulator combined with VR (see Figure 1), it is possible to experimentally compare high-risk sport participants with non-risk sports activity participants. As a proof of concept, Zimmer and colleagues⁴⁰ used the *Trier Social Stress Test* (TSST) to demonstrate that stress exposure in VR initiates psychophysiological reactions (e.g. salivary cortisol, salivary *alpha-amylase*, and biofeedback data) that are comparable to reactions experienced under real conditions. Furthermore, Fadeev and colleagues⁴¹ established extreme-stress scenarios in VR to measure participants' reactivity of the autonomic nervous system which responded with acute stress responses. In sum, the experimental setting of *StressVR* will allow us to 1) minimize the personal risk of the participants for injuries, 2) maximize the standardization of the VR exposure, and 3) collect saliva samples to measure biomolecular stress markers during a wing-suit experiment.

Figure 1: Schematic representation of the VR wing-suit simulator setting. The participant is secured with ropes connected to a belt surrounding the chest. The angle of the participant's position can be controlled using an electromechanical motor during the VR wing-suit flight. Aerodynamics are additionally simulated by ventilation to intensify the VR experience.

2. Methods

2.1 Recruitment and study inclusion of participants

The study protocol of *StressVR* was already approved by the local Ethical Reviewboard at the Leopold Franzens University Innsbruck. Three different experimental groups will be recruited: 1. *Professional high-risk sports athletes* performing on a professional level (i.e. competitive athletes who have salaries, bonuses, advertising contracts, and/or sponsoring), 2. *Non-Risk sports athletes* practicing one or more non-risk sports on a regular, intensive level, and 3. *Non-Athlete controls* who are not interested in regular exercise on a competitive level⁴². For each group, 50 male individuals will participate. To consider robust findings of endocrine changes with increasing age and *body mass index* (BMI)⁴³, participants between 18 and 55 years will be

included in the study. Exclusion criteria are any previous experience of wing-suit flying, a present or past mental disorder, current drug use, critical or traumatic life events within the past four weeks before study participation, and a documented clinical history of seizures. Additionally, individuals with existing binocular visual impairments or a documented cardiovascular risk or disease or other serious illnesses will be also excluded from the study. All participants will provide written informed consent before the laboratory experiments.

2.2 Assessment of sociodemographic, behavioral, and personality characteristics

On the day before the laboratory appointment, participants will be asked to use the "SosciSurvey" platform for answering a personality and an anamnesis questionnaire as well as the *Risk-Taking Inventory*⁴⁴ (RTI) and the *State-Trait Anxiety* questionnaire (STAI)⁴⁵. The STAI is used for investigating habitual anxiety, the state of current anxiety, and the confrontation with personal fears⁴⁶. Additionally, the following questionnaires are also answered online before the laboratory experiment: The *Accidents and Close Calls in Sport Inventory* (ACCSI)⁴⁷, the *Big Five personality Inventory* (NEO-FFI), *Childhood trauma questionnaire* (CTQ; Adverse childhood experiences⁴⁸), the *Essener Trauma Inventory* (ETI; Critical and traumatic life events in adulthood⁴⁹ and the *Brief Symptom Inventory* (BSI)⁵⁰. The ACCI is a questionnaire by Barlow and colleagues⁵¹ to measure experienced accidents and close calls. Personality traits will be assessed with the *NEO-FFI*. It categorizes individuals into the five factors "conscientiousness", "agreeableness", "neuroticism", "extraversion" and "openness"⁵².

2.3 Adverse childhood experiences and traumatic life events in adolescence and adulthood

Bernstein and Fink⁵⁴ developed the *Childhood Trauma Questionnaire* (CTQ), which became an accepted standard in psychological stress research and the clinical field⁴⁸. It includes 25 items, each offering a *Likert* scale ranging from 1-5. The CTQ measures adverse childhood experiences on five different dimensions: Emotional, physical, and sexual abuse as well as emotional and physical neglect (CTQ sum scores range from 25-125 accordingly). In addition to the assessment of critical and traumatic life events until the age of 18, the *Essener Trauma Inventory* (ETI), developed by Tagay and colleagues⁵⁵, will be used to assess traumatic life events during adolescence and adulthood. The ETI includes 28 items using *Likert* scales as well as dichotomous answering possibilities. The *Brief Symptom Inventory* (BSI) is used to evaluate psychological strain and stress. As a self-report questionnaire, it is used to assess symptoms of somatization, compulsivity, insecurity in social contact, depression, anxiety,

aggressiveness/hostility, phobic fear, paranoid thinking, and psychoticism measured with a total of 18 items^{50,56}.

2.4 Assessment of attachment representations

The AAP is a valid and reliable measure for classifying four different groups of attachment: “Secure”, “dismissing”, “preoccupied” and “unresolved”²³. Attachment classification is implemented by analyzing the individual’s free responses to a set of seven attachment-related picture stimuli depicting scenes of solitude, death, separation, and fear designed to activate the attachment system in different settings^{23,32,36,57}. Responses are evaluated through a coding system comprising three dimensions: Discourse (self-other boundary), story content (agency of self, connectedness, synchrony), and defensive processing (deactivation, cognitive disconnection, segregated systems)^{26,58,59}. As depicted in Figure 2, the AAP procedure will be performed in the laboratory on the same day before the VR experiment.

2.5 Peripheral stress markers and biofeedback parameters

Peripheral stress markers including heart rate (HR), heart rate variability (HRV), skin conductance (SC), and respiratory rate (RR) will be recorded by one single device (Mindmedia Nexus 10, Netherlands). Participants will be connected via ECG electrodes, finger sensors, and a chest belt to measure RR. Biofeedback is an ongoing response to physical processes that cannot be controlled consciously⁶⁰. HR implies the contraction of the heart muscles which ranges from 60 to 90 beats per minute (bpm) in a resting situation⁶¹. The HRV is the ability of the heart to react to different influences with temporal beat-to-beat changes⁶². The electrodermal activity, represented in the SC, is controlled by the sympathetic nervous system which is part of the vegetative nervous system. It controls sweat production, which evolutionary promotes a better attack and escape behavior. Changes in tension can indicate arousal or activation through stress⁶³. At rest, the physiological RR is about 15 respirations per minute⁶⁴. Now, in stressful situations, the breathing rate changes autonomously, and the RR increases, which is also necessary for a higher oxygen supply of the body’s energy production⁶¹. The body reacts to stress with the adaption of these processes which will be co-measured in *StressVR*.

2.6 Collection and processing of saliva samples

Due to circadian rhythm, concentrations of cortisol and *alpha-amylase* activity levels vary over the day^{66,67}. To standardize the laboratory conditions as best as possible, experiments will be standardized to the same daytime (10 a.m.), examining one participant per day. Participants will

be asked to provide four saliva samples collected with commercially available saliva sampling tubes (Sarstedt, Nürnberg, Germany) during the entire experiment (see Figure 2 for a graphical representation of the workflow procedure). Saliva samples for the measurement of *alpha-amylase*, pH values, beta-endorphin, and cortisol will be taken before (t_0), during (t_1), and after the experimental procedure (t_2) as well as after 30 min following the experiment (t_3 post). Measurements of cortisol, beta-endorphin, and *alpha-amylase* activity will be performed using spectrophotometry technology. Values will be assessed in duplicates and averaged data will be used for statistical analyses. For the measurement of *alpha-amylase* activity, cortisol and beta-endorphin commercially available enzyme-linked immunosorbent assays and spectrophotometrically kits will be used, respectively. As both test systems to measure cortisol and *alpha-amylase* depend on the reactivity of antibodies and enzymes, respectively, we will additionally measure pH in saliva to control for possible confounder effects of stress-induced changes in pH on enzymatic readouts and antibody specificities for the selected cortisol antigen. Therefore, immediately after sampling, pH in saliva will be measured using pH-test strips appropriate for saliva samples.

2.7 VR wing-suit flight

The central part of the study implies a wing-suit flight presented in VR, experienced with a wing-suit flight simulator and a high-quality VR headset. The camera mounted on the head of the pilot who recorded the video sequence enables the test subjects to take the pilot's virtual position. As another innovative and exclusive feature of *StressVR*, the study participant will not only be exposed to visual but also to vestibular stimulation to maximize the VR experience (see Figure 1). The video content will be new to all participants. At the beginning of the video, a hiking situation on a mountain terrain is presented. This first film scene, which lasts approximately 5 minutes, is shown to sensitize and regulate possible motion sickness, a known technological limitation in VR. It is also used as a baseline for the comparison with the stress exposure during the wing-suit flight. Just before the VR flight, the position of the participant is controlled as the simulator goes first directly to the same position as the pilot's flight position when the test person/pilot takes off. Now, the self-developed electromechanical support system not only secures the test person but also uses different "support points" to distribute the bodyweight so that the participant gets the impression of being almost weightless. Additionally, the system appears unstable, as it allows degrees of freedom in all directions. The simulator reacts to the pilot's movements at different time points during the flight so it can mimic kinetic

energies like motion and velocity. The virtual flight lasts approximately 80 seconds and includes emotionally thrilling flight actions including flying through an arch of rock. At the end of the movie, the pilot opens the parachute and performs a safe landing. For an even more realistic presentation, the VR simulator is additionally equipped with a ventilation system to mimic aerodynamics during the flight. In sum, the technical set-up of StressVR enables the participants to get the best possible sensation of a realistic wing-suit flight. Other existing flight simulators, for example, the Icaros™ platform, use hydraulic systems but do not provide a comparable degree of freedom in the movement of the participant. A graphical representation of the study work-flow is given in Figure 2. Summarizing *StressVR*, the results of the study will allow us to extend the current understanding of the complex interaction of personality, critical life events, psychobiological stress responses and attachment representations in the context of high-risk sports.

Figure 2: Schematic representation of the study workflow of *StressVR*. After the recruitment of participants, inclusion and exclusion criteria are applied. Next, sociodemographic and psychological variables are assessed, followed by the *Adult Attachment Projective Picture System* (AAP) to determine attachment representations. During the VR wing-suit experiment saliva samples are collected at four subsequent time points (t0-t3) using Salivette tubes (blue

lid) including a sterile cotton pad. Biofeedback signals include heart-rate variability (HRV), heart-rate (HR), skin conductance (SC) and respiration rate (RR).

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