Ulster Med J 2023;**92(3):**157-166

Medical Education

Untapped resource: the simulation-based healthcare environment as a means to study human stress.

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ABSTRACT

The effects of 'stress' within the healthcare professions are wide-reaching, not least of all within the field of simulation-based healthcare education. Whilst this popular method of experiential learning offers a 'safe space' for participants to develop their skillset, it also has a more surreptitious action; namely, the incubation of simulation-related stress. Currently, research concerning the complex relationship between stress, learning, and performance is ambiguous, leaving fertile ground for simulationists to debate what level of stress is appropriate for an optimised educational experience. In this narrative review, we examine the human response to stress and outline the various methods that have been used by researchers to measure stress in a quantifiable and standardised way. We then provide a brief overview of simulation-based healthcare education before describing why stress responses have been of interest to healthcare educationalists for some time. Finally, we outline how simulation education environments might provide an ideal environment for studying the human response to stress generally, with ramifications extending beyond the field of medical education.

Introduction

The field of healthcare is often associated with the term 'stress.' In their 2021 report, the United Kingdom's General Medical Council stated that, "The COVID-19 pandemic increased burnout among doctors and risks reversing improvement in their workloads and wellbeing" [1]. The effect on medical students, and indeed all healthcare professionals, is unlikely to be different. Accounts of student stress are well documented in the literature, often being associated with factors such as social evaluation (assessment in front of peers), the presence of senior staff (perceived judgement), and feelings of incompetence [2,3,4]. Stress is, of course, ubiquitous and familiar to all individuals in society, not simply healthcare professionals. Much research has been carried out examining the human stress response in different situations, but relatively little has been done in healthcare scenarios. Simulation is a widely used experiential process within healthcare institutions, where errors do not have the same clinical implications as in the real world [5]. However, as with real-world scenarios, simulation has the ability to evoke a plethora of biological, cognitive and emotional responses. These responses can all exert influences on learning and performance [6]. Stress research in healthcare simulation fields has largely focused on how acute stress might either impair or improve learning and performance, depending on the individual, the stressor and the individual's appraisal of the stressor [7,8]. Opposing schools of thought argue whether high-stress or low-stress environments are most conducive to an optimised healthcare education experience [9].

This review will examine the general human response to stress and outline the various methods that have been used by researchers to measure stress in a quantifiable and standardised way. We will also examine ways in which stress has been artificially generated in an experimental setup. We will proceed to provide an overview of simulation-based healthcare education and the research that has been done looking at the differing effects stress can have on a learner. Finally, we propose that healthcare simulation environments provide an excellent environment in which to examine the human stress response, both as it relates to healthcare and education, but more generally to the study of human behaviour. This is a narrative review, not a systematic review. Sources of information were obtained by searching OVID Medline and Embase for relevant articles in the human literature, and by reviewing the reference lists of papers obtained by these methods. We have attempted to provide readers with a balanced overview of these topics, acknowledging that the search strategy employed is less robust than that which would be employed in a systematic review.

Stress

Before its entry into the common vernacular, the word 'stress' belonged to the field of mechanical engineering, as a means to describe the behavior of materials under load. However, today it may be thought of as an umbrella term, aiming to

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portray the complex relationship between the environmental demands, resources, perceptions and responses of an individual or group [10, 11, 12].

Fight or flight

The early twentieth century saw the American physiologist, Walter Cannon, first annotate his hypothesis of homeostasis, describing the regulation of blood glucose, core temperature and oxygen tension within defined physiological ranges. During consequent years of research, Cannon further postulated that there were many threats to homeostasis, eliciting retaliatory responses from the adrenal medulla and sympathetic nervous system (SNS), in an attempt to restore balance; the 'fight or flight' stress response was conceived [13,14].

General adaption syndrome

Whilst Cannon has often been suggested as the first to use the term stress in a biological context, it was popularized within the wider fields of science by the Hungarian Canadian endocrinologist, Hans Selye, in his 1936 paper describing the reactions of animals to a variety of noxious compounds – General Adaption Syndrome (GAS) being the consequent name given to those reactions. GAS is comprised of three stages: (i) alarm reaction, (ii) resistance and (iii) exhaustion. The alarm reaction precipitates SNS activation in the presence of a stressor, eliciting a fight or flight response. Resistance occurs when a persistent stressor is congruent with the process of adaption, nullifying the alarm reaction. Exhaustion occurs during chronic exposure to a stressor, impacting homeostasis and eventually leading to multisystem dysfunction [10].

Allostasis and allostatic load

On determining that the traditional idea of homeostasis would not suitably reveal the cumulative impact of chronic stress on the human body, McEwen and Stellar (1993) [15] adopted the term 'allostasis' from a chapter by Fisher and Reason, in Sterling and Eyer's 1988 handbook on arousal pathology [16]. Essentially, McEwen suggested that homeostasis in the face of a stressor (or stressors) was maintained through brain-coordinated body-wide variation, as opposed to the maintenance of an optimum value via local regulation. Allostasis, meaning homeostasis through change, describes the fluctuating physiological nature of the human body and constituent biochemical mediators such as catecholamines and glucocorticoids. The term 'allostatic load' subsequently followed, to describe the cumulative damage incurred during consecutive cycles of allostasis [12]. Using the MacArthur study of successful aging (a comprehensive study evaluating factors associated with living longer whilst avoiding major disability) Seeman *et al*. (2001) [17] developed a multi-marker approach to allostatic load, evaluating its ability to predict the health outcomes of subjects (n = 1,189) aged between 70 – 79, seven years after baseline testing. Seeman and colleagues have found that individuals displaying higher baseline allostatic load exhibit a significantly higher risk of mortality in the subsequent seven-year period. Several recent studies have successfully utilised a multi-marker approach to allostatic load as a measurement of chronic stress [18,19], validating the combined use of multiple markers to evaluate stress.

Response physiology

Appraisal of a stressor as threatening stimulates both the sympathetic-adrenal-medullary (SAM) and hypothalamic-pituitary-adrenal (HPA) axes (Figure 2). The SAM axis mediates a rapid response (seconds to minutes), elevating adrenaline and noradrenaline secretion from the adrenal medulla and adrenergic/noradrenergic neurons. On binding to either α- or β-adrenoceptors, adrenaline and noradrenaline elicit G-protein-mediated cyclic adenosine monophosphate (cAMP) signaling pathways, causing arterial vasoconstriction, increased heart rate, blood pressure and cardiac myocyte contractility [20]. The HPA axis mediates a slow response (minutes to hours), triggering the release of corticotropin releasing hormone (CRH) from specialised neurons in the hypothalamus. This influx of CRH prompts the secretion of adrenocorticotropic hormone (ACTH) from the anterior pituitary gland via interaction with CRH-1 and -2 receptors, stimulating the adrenal glands to release glucocorticoids, such as cortisol, into the bloodstream. This co-activation of the SAM-HPA axes enables the body to mount a fight or flight stress response [21]. The human stress response has evolved towards short-term gain; the activation of a number of systems to evade or address an impending stressor. However, in the era of the modern human, behavioral, cognitive and emotional evolution has far exceeded the scope of the archaic stress response; an apt example may be that merely thinking about a potential stressor will often elicit an accompanying stress response.

The interplay between stress, memory and learning

According to Xu *et al*. (1998) [22], the hippocampus and the amygdala are heavily concentrated with two predominant types of glucocorticoid receptors (type-1 and -2). During basal, low-stress environments, type-1 receptors are mainly occupied by any free cortisol molecules in the limbic system, encouraging increased synaptic plasticity (enhanced neuro-electrical activity, conducive to hippocampal-related memory). However, as an individual perceives the environment as increasingly stressful, cortisol molecules begin to bind to type-2 receptors, until binding equals type-1 receptor binding in high-stress states [23]. Essentially, high-stress environments increase glucocorticoid receptor affinity for cortisol in the limbic system. This increase in glucocorticoid receptor binding can reduce synaptic plasticity in the hippocampus whilst increasing it in the amygdala [24]. Over time, the emotionally charged, fearful amygdala may increasingly influence memory formation in states of high stress. This may well explain why people remember a lot about 9/11 but very little about 9/10.

Stress measurement

Stress can be measured in terms of stressor exposure (occurrence of events with the ability to disrupt psychological function) or stress response (cognitive, emotional, and physiological reactions to said events). Self-reported questionnaires such as the perceived stress scale (PSS) or state-trait anxiety inventory (STAI) may be used to measure stressor exposure, with both aiming to capture an individual's perception of how overcome they feel concerning the current situation. In contrast, biochemical and physiological markers may be used to measure the stress response in an objective manner [25].

Quantifying perceived stress

Measuring stress through the act of 'self-reporting' is commonplace in research evaluating the environmental and/or psychological aspects of a stressor (or stressors) on an individual (or group). Three established methods used to measure perceived stress and anxiety are the impact of event scale, STAI, and PSS; of which the PSS is the most common method employed in research studying stressful events [26]. The original PSS, developed by Cohen and colleagues (1983) [27], is a 14-item scale evaluating an individual's perception of events occurring in the previous 4-weeks. Participants are asked to rate items on a 5-point Likert scale. Interestingly, Malarkey *et al*. (1995) [28], found that daytime plasma cortisol levels are increasingly elevated during examinations in students who scored higher on the PSS. However, whilst this research suggests a correlation between self-reported and biochemical measures of stress, there are many studies that show a more ambiguous relationship [29,30,31].

Measuring the biochemical response to stress

It has long been acknowledged that psychological stress precipitates physiological change, which is detectable in a variety of biochemical tests. Stress physiologists, both past and present, have studied an array of compounds in an attempt to find the holy grail – a marker revealing the blueprint of psychological stress. Some of the most commonly studied markers are discussed in the following paragraphs.

Adrenaline and noradrenaline

There are several practical considerations when using these compounds to track stress. Firstly, the anxiety and/or pain associated with venipuncture may trigger a systemic rise in levels, thus confounding results. Secondly, the short biological half-life of both plasma adrenaline and noradrenaline may give rise to issues in terms of acquiring a sample indicative of participant stress in the moment. The metabolites metadrenaline and normetadrenaline may be used to offer a greater window of opportunity regarding sample collection [32]. It is worth noting that a variety of medications and foods, as well as vigorous exercise or exposure to extreme temperatures are not recommended prior to catecholamine testing.

Cortisol

Due to the relative ease with which cortisol can be measured, it has become a commonly used marker of both acute and chronic stress. In studies analysing psychological stress, salivary cortisol has become a popular metric in recent years [33,34], perhaps because samples can be acquired easily without the need for phlebotomy. However, challenges relating to the COVID-19 pandemic have made salivary cortisol collection more problematic, due to concerns about infection control.

Adrenocorticotropic hormone

As rising ACTH levels induce a proportional increase in cortisol secretion, they share a similar diurnal pattern [35], therefore, testing is recommended in the morning.

Dehydroepiandrosterone

Both dehydroepiandrosterone (DHEA) and DHEA-S (its sulfated metabolite) have been shown to be noteworthy biomarkers of acute stress [36,37].

Salivary α-amylase

Salivary α-amylase (sαA) is known to be an agent of autonomic nervous system (ANS) activity, due to being the principal salivary enzyme secreted via sympathetic stimulation; hence its increasing use as a biomarker of stress [38,39]. SαA secretion is mediated by the SAM pathway, displaying a diurnal pattern inverse to that of cortisol; a sharp decline upon waking with continued elevation throughout the day.

Measuring the physiological response to stress

As previously touched upon, it is widely accepted that psychological stress can induce physiological changes. However, these responses to stress can elicit any number of effects on device-based readings in a clinical setting. For example, white coat hypertension (elevated 'in clinic' blood pressure due to increased patient anxiety) is one well known manifestation of the human stress response. Researchers in the field of stress biology have studied a wide range of physiological responses. Some of the most widely studied metrics are discussed below. Technological innovations in recent years means that it is now quite possible to fit a person with a number of ergonomically acceptable sensors prior to undertaking a simulation. Some parameters (like heart rate) can be tracked in real-time whilst others (e.g., blood pressure) are measured at defined intervals.

Blood pressure

Blood pressure (BP) is the force exerted upon the interior wall of arterial vessels by circulating blood. Systolic blood pressure (SBP) is measured during cardiac contraction, when pressure is greatest, and diastolic blood pressure (DBP) is measured during cardiac relaxation, when pressure is least. During a typical stress response BP will increase due to the

vasoconstrictive, as well as the positive chronotropic and inotropic effects of adrenaline and noradrenaline on the arteries and heart, permitting the delivery of blood at a higher velocity to working musculature. BP can be monitored via an electrical occlusion cuff or by a manual occlusion cuff and auscultation [40]. It is well appreciated that psychological stress can elevate BP, and for that reason all guidelines on BP assessment mandate that the subject sits quietly at rest before measurements are taken [41].

Heart rate

Heart rate (HR), or pulse rate, is the number of cardiac contractions in one minute. During a stress response HR will increase, again, due to the positive chronotropic effects of adrenaline and noradrenaline on the heart, allowing more nutrient-rich blood to reach targeted tissues in anticipation of work. HR is most accurately measured via electrocardiography (ECG) [42], but wearable HR monitors and manual palpation are commonly used. In their study on the impact of social evaluation on student performance, Mills and colleagues (2016) [2] show that mean HR increases by 10 beats/min between scenarios involving one and three people, respectively; further suggesting that performance in front of a larger audience elicits a heightened stress response. This suggests there are strong physiological reactions in the classic psychological phenomena of social facilitation [43], and evaluation apprehension [44].

Heart rate variability

Heart rate variability (HRV) describes the variation in time intervals between heart beats. These oscillations are governed by the ANS, aptly described by chaos theory, and mirror fluctuations in BP, respiration, and vascular tone, amongst other integral systems [45]. Frequency-domain methods evaluate HR oscillation frequency via division into one of four bands – ultra-low (ULF: <0.003 Hz), very-low (VLF: 0.0033 – 0.04 Hz), low (LF: 0.04 – 0.15 Hz), and high frequency (HF: 0.15 – 0.4 Hz); expressed in units of absolute (m^2/Hz) or relative power (nu). LF and HF bands are the most common HRV indices employed in stress-related research due to their associations with sympathetic and parasympathetic activity. Time-domain methods analyze variation within the inter-beat interval (IBI). The standard deviation of NN intervals (between normal R wave peaks, artefacts removed) (SDNN) and root mean square of consecutive NN differences (RMSSD, root of the mean difference between NN intervals squared) are often used in stress-related studies due to their correlations with LF and HF bands. There is, however, controversy in the literature as to the efficacy of HRV as a tool to measure stress. This disagreement stems from the notion that the elevation and subsequent decline of HR during respiration significantly impacts HF oscillations whilst diminishing LF power. For example, in a 2020 study on stress and anxiety during resuscitation simulation, Stein [31] reports that HRV is not an effective measure of stress, as it fails to identify any significant variation from those at rest. In contrast, Nakayama *et al*. (2018) [3] show that events perceived as stressful increase HF whilst decreasing LF/HF, indicating elevated sympathetic activity. Taking all into account, the nature of a simulation may in itself create confounding factors – simulations requiring increased physical exertion (e.g., CPR) and/or verbal engagement may invalidate HRV data.

Galvanic skin response

Galvanic skin response (GSR), or electrodermal activity, refers to variations in the electrical activity of the skin. This activity may be measured by applying an electrical current to a region of skin, between two electrodes, and analyzing electrical conductance. Skin conductance level (SCL) describes a mean GSR over a longer period of time, whereas skin conductance response (SCR) refers to phasic changes in electrical activity [46]. The mechanisms governing psychological, or emotional, sweating are incompletely understood. It is thought that during periods of acute stress, acetylcholine is the predominant mediator of eccrine sweating, whilst adrenaline and noradrenaline may elicit apocrine sweat gland activation. Therefore, an increase in conductance would indicate elevated SNS activity in response to a stressor [47]. In their 2020 study evaluating the efficacy of GSR in distinguishing stress responses within simulated driving scenarios, Daviaux and colleagues [48] state that GSR amplitudes are significantly associated with subjective experiences of stress. In recent years, several studies have suggested that GSR may be an effective single physiological measure to detect stress, as opposed to multi-marker models such as allostatic load [49,50]. However, it is worth noting that whilst GSR is a respected marker for SNS activity, not every individual will perspire accordingly in relation to psychological stress. Additionally, the conditions of hyperhidrosis and anhidrosis in which people sweat excessively or not at all respectively, may complicate matters.

Inducing stress in experimental settings

There are many environments one can simulate to induce stress. Noise, temperature, time constraints, human factors, and social assessment are several examples. However, in spite of the methods employed, there is one central element: a lack of predictability. Fostering a human being's belief that their immediate environment is something they have little to no control over often elicits a stress response of substantial magnitude [51,52]. An interesting, but draconian, study conducted by Seligman and Meyer shows a very real-world outcome concerning a lack of predictability. In this study, two groups of rats received intermittent electric shocks. One group heard a warning siren prior to the shock, the other did not. Intriguingly, the rats who heard the siren were less likely to develop stress-related stomach ulcers than their counterparts [53]. Obviously, this vein of research from the 1970s goes well beyond what we would deem as ethically appropriate in today's climate. Nonetheless, it's a stark reminder of both the simplicity and power of unpredictability.

Simulation-based healthcare education

A brief history

Simulation has been deeply embedded within medical education for some time. The technological revolution of the twenty-first century acted as an evolutionary catalyst for simulation-based healthcare education (SBHE), but the origin of the 'simulator' can be traced back to seventeenth century Paris, in the form of a macabre infant and pelvis pairing used by Gregoire and Son as midwifery training specimens [54]. The nineteen-sixties ushered in the era of 'modern' SBHE, with advances such as 'Resusci-Anne' and 'Harvey' – cardiopulmonary resuscitation (CPR) and cardiology simulators, respectively. Innovations in computer software throughout the early twenty-first century paved the way for the high-fidelity mannequins used in medical simulations today [55].

Structure

Whilst each training centre will develop its own plan regarding SBHE, there are three common phases in a simulation: Brief, Simulation, Debrief. During the briefing phase, educators aim to reduce learner anxiety by introducing the simulation landscape and constituent simulators. The simulation phase involves participation in a designed scenario, ranging from the diagnosis of a somatic condition by taking a history (e.g., diagnosing a respiratory tract infection in a person with a cough), to involvement in an emergency situation (e.g., CPR). The debriefing phase is traditionally a post-simulation feedback session, where educators encourage learners to share their emotional responses and thought processes concerning the simulation, allowing reflection and informed discussion in terms of learning and performance [56]. The debriefing phase can further be divided into three subphases, (i) reaction, (ii) analysis and (iii) summary. The reaction subphase encourages learner self-expression. Analysis is generally composed of a formative assessment, whilst the summary delivers critical key messages and points of improvement [57]. It should be noted that the use of intra-simulation debriefing has also been validated as a tool to aid learner understanding [58]. One could envisage how this technique may enable the simulation structure to be altered ad hoc, based on the analysis of real-time biological and/or psychological data, essentially changing the simulation landscape to suit the needs of the learner. However, whilst intra-simulation debriefing permits real-time variation, it may reduce the overall fidelity of the simulation.

Aim and validity

Creating a learner-focused environment, where errors do not have the same clinical implications as the real world, is the overarching aim of SBHE [5]. Proponents of healthcare simulation believe that engagement with this environment will improve education and performance, in comparison with the 'sink or swim' nature of real-world learning [59,60]. The use of SBHE has been validated in several studies [61,62,63]. In their guide to simulation-based medical education, Motola and colleagues (2010) [62] state that simulation has exploded into the medical field, with its use growing in an exponential fashion. Similarly, Sakakushev *et al*. (2017) [63] conclude that simulation may cause a paradigm shift that could change medicine, for the better. In their paper discussing the validity of medical simulation, Wang *et al*. (2013) [64] state that due to the repeatable nature of simulation scenarios students can normalize procedures, leading to an increased skillset and improved assessment results. However, despite its growing status as an effective tool for healthcare education, simulation has the potential to evoke a variety of cognitive, emotional and physiological responses in the individuals' taking part. The way a stressor is perceived by an individual may initiate a complex cascade of mechanisms that can either enhance or hinder learning and performance [6]. Thus, in addition to helping students and practitioners improve their skills, SBHE affords the opportunity of studying human behavior in a controlled and reproducible environment.

Stress, learning, and performance

Imagine taking several healthcare students and subjecting them to a scenario they deem as traumatic. What you may find is that they remember the blood, the noise, the patient convulsing, the senior staff shouting; but what about intubation, compressions, dosages or drug interactions? The inverted U (Figure 1) created by the Yerkes-Dodson law is often cited as a schematic that represents the relationship between an increasing stressor and its impact on any number of outcomes [65]. A stressor acting as a stimulus for more salutary outcomes is the aim when it comes to optimizing both learning and performance. However, too far to either left (under-stimulated) or right (over-stimulated) will expose the learner to a range of increasingly deleterious effects. For example, introducing a first-year medical student to an emergency resuscitation simulation will likely cause hyperstimulation, resulting in diminished performance and significantly reduced learning capacity. On the other hand, selecting a more appropriate simulation for a first-year student (e.g., taking a straightforward medical history) should optimize stressor-mediated stimulation, creating

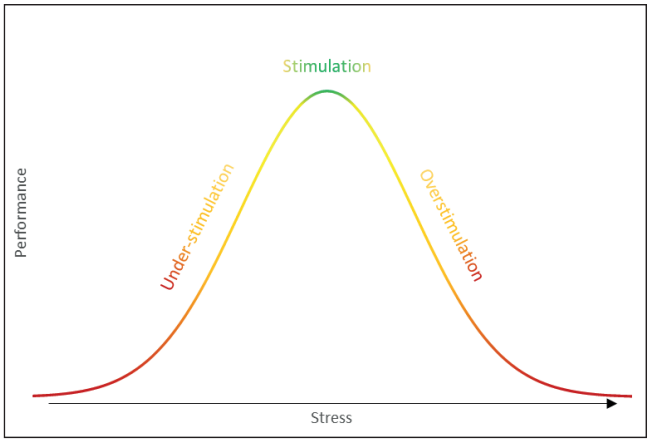

Figure 1: Inverted U curve created by Yerkes-Dodson law.

a more conducive environment for both learning and performance. Conversely, if a student is under-stimulated by the simulation, learning and performance may also suffer.

Research into the effects of stress on performance within the field of SBHE has been steadily growing over the last decade. However, the results are inconsistent. The complex nature of human interaction creates an expansive landscape to study, meaning that popular terms such as 'stress,' 'learning' and 'performance' are inherently labyrinthine despite their verbal simplicity. Given the number of ways in which stress can be measured, and paired with the personality, beliefs, and perceptions of an individual, it isn't surprising that the literature argues that stress can either impair, enhance or have little effect on performance.

Impaired performance

In essence, learning and performance are two sides of the same coin, and one could argue that performance is the metric by which learning is measured. However, both learning and performance are susceptible to the influences of stress. A common theme regarding stress and impaired performance is participation in environments of high psychosocial stress – such as those characterized by increased cognitive load (e.g., public speaking). It should be noted that studies employing a wider range of measurements show an improved likelihood of identifying relations between stress and performance. In their study evaluating the impact of social evaluation anxiety on student performance during medical simulation, Mills and colleagues (2016) [2] report that salivary cortisol exhibits significant differences between simulations with one vs. three onlookers (-0.05 vs. 0.11 μg/dL; p = 0.02), further stating that students accompanied by one person outperform those accompanied by three people (12.95 vs. 10.67 marks; p = 0.03). LeBlanc et al. (2005) [66] found that high-stress (HS) simulation conditions are associated with lower accuracy drug dose calculations, in comparison with low-stress (LS) conditions (HS: 43%; LS: 58%), in their study analyzing the effect of stressful simulation scenarios on paramedic calculation performance. Fraser and colleagues (2014) [67] show that students in scenarios where a simulated patient dies unexpectedly report a higher cognitive load than those in scenarios where the patient survives; in an objective structured clinical examination (OSCE) three months later, it was found that students who witnessed the simulated patient death were less likely to have rated above the minimum pass level. Considering other fields than SBHE. Kuhlmann et al. (2005) [7] report that higher cortisol levels are associated with poor word recall in environments of elevated psychosocial stress, in their study investigating impaired memory retrieval (stress recall: 56.80 ± 4.01% of words; control recall: 64.17 ± 4.76% of words). In their study on psychosocial stress and working memory, Oei and colleagues (2016) [68] report that high levels of psychosocial stress impairs working memory; also indicating that high cortisol levels (stress: 34.4 nmol/L vs. control: 14 nmol/L; p = 0.01) are associated with slower working memory performance. Cooke *et al*. (2010) [69] found that moderate- and high-stress conditions are significantly associated with the number of successful putts, in their study on the psychological, muscular, and kinematic factors of golfing performance under-pressure. As previously mentioned, an individual's perception of a stressor will significantly influence the stress response. In terms of this stressor appraisal, Vine and colleagues (2015) [70] discovered that a threat reaction to a stressor is associated with poor performance and impaired attentional control, in their study assessing the impact of stress reactions on performance in critical aviation incidents.

Enhanced and unaltered performance

Some research suggests that simulation-related stress may not alter performance. However, there are few, if any, studies that show improved performance. One common theme concerning stress and enhanced, or unaltered performance is the level of physical exertion during assessment tasks. Regehr *et al*. (2008) [8] report that individuals displaying higher cortisol levels outperform colleagues who exhibit lower levels, in their study evaluating the impact of acute stress on police recruits. During the study recruits were presented with a domestic situation in which they had to physically apprehend a suspect. Also, Vicente-Rodriguez and colleagues (2020) [71] show that increased sympathetic modulation does not elicit any negative effects on cognitive or muscular performance during underwater aircraft evacuation training – in which participants had to swim, enter a submerged helicopter, and rescue aircraft personnel. In their study on psychological stress versus physical stress, Ponce *et al*. (2019) [72] conclude that neither vigorous exercise nor psychosocial stress significantly impact working memory performance despite producing similar cortisol responses. Research clearly shows a relationship between stress and performance when the mode of stress is considered. Environments of high psychosocial stress composed of tasks characterized by low physical exertion, increased cognitive function, and/or fine motor skills show association with diminished performance, specifically information retrieval. In contrast, enhanced or unaltered performance shows association with increased levels of physical exertion during assessment tasks.

Stress and personality

Research in the field of healthcare simulation has generally failed to address the influence of personality on a dataset. Within any group there will be a variety of personality types, all perceiving stress in differing fashions depending on their development, beliefs, perceptions, and genetic predispositions. Categorization of data according to personality traits may well reveal relationships between the pillars of stress, learning, and performance that would remain otherwise undetected. A study by Oswald and colleagues (2006) [73] found that higher levels of neuroticism in women and lower levels of extroversion in men are associated with blunted cortisol responses during stressful psychosocial environments – revealing not only a possible personality

factor, but a possible gender factor regarding personality traits and stress responses. In their study investigating the relationship between personality and stress response, Xin *et al*. (2017) [74] show that individuals with higher neuroticism display lower cortisol responses and an accelerated decline of positive affect, whilst those displaying higher extroversion also display lower cortisol stress responses but have less increase in negative affect. Karnik *et al*. (2018) [75] report that incarcerated juvenile delinquents with non-reactive personality traits display significantly lower responsiveness to stressors and reduced overall arousal. Non-reactive personality types are defined as low distress, low restraint individual's, likely displaying elevated rates of anti-social behaviour accompanied by little remorse for their actions. Childs and colleagues (2014) [76] state that subjects with tendencies toward alienation and situational anxiety show greater emotional distress and blunted physiological response to psychosocial stress, whilst subjects with tendencies toward assertiveness and social dominance display prolonged HR recovery after psychosocial stress. LeBlanc and Ducharme (2005) [77] reveal that extroversion and cortisol levels show a positive relationship, whilst neuroticism and cortisol levels display a negative relationship, in their study analysing the effect of personality traits on plasma cortisol levels. Research evidently supports the notion of different personality traits exhibiting a diverse range of stress responses to a variety of stressors. A fascinating study by Inukai *et al*. (2010) [78] found that neuroticism and agreeableness show positive and negative correlations with sαA, respectively – indicating that subjects with differing personality types may well have varying baseline levels of stress-related biochemical markers.

Stress-reduction interventions

The relationships between stress, learning, and performance are complex, to say the least. However, stress-reduction interventions are an avenue of research accepting the intricacies of the stress response whilst aiming to improve both learning and performance by implementing techniques such as meditation, deep breathing, and intra-simulation debriefing. Proponents of stress-reduction interventions within healthcare simulation believe that the deleterious psychological and physiological effects of the stress response may be mediated by the previously mentioned techniques, thus, creating an improved environment for learning and performance [79,80]. Research concerning the use of stress-reduction interventions is sparse, and findings are mixed regarding the impact of such interventions on learning and performance. Schober *et al*. (2019) [58] found no significant differences in assessment performance between intra- and post-simulation debriefing, whilst Lilot *et al*. (2018) [57] conclude that a 'relaxation break' prior to post-simulation debriefing increases the recall of key messages by 25%, three months after learning them. Although findings have been mixed, the self-reported aspect of several studies indicates that participants find stress-reduction interventions beneficial. In their study trialling 'pause button' debriefing, McMullen and colleagues (2016) [79] report that 88% of participants support the integration of 'debriefing-on-demand' into further medical simulations due to its positive effects on feelings of stress and anxiety. Furthermore, Merriman *et al*. (2021) [80] show that participants, who engage in a stress recovery intervention post-simulation, have a significantly higher self-reported potential to manage stress in the following simulation. More research is required to further understand the supposed benefits of stress-reduction interventions on stress mitigation, learning, and performance within SBHE. These techniques may create easily integrated, cost effective methods to manage simulation-related stress and improve overall learning and performance.

Simulation-based healthcare education: A ripe environment for stress research

By virtue of being tailor-made for their role as educational facilities, SBHE departments boast an excellent environment in which to conduct stress-related research. In terms of aesthetic appearance, SBHE departments often resemble research laboratories for human studies. Such departments necessitate medically trained members of faculty, which is of tremendous benefit for studies requiring phlebotomy. Many of the tools commonly used in stress research can be easily accessed in SBHE departments (e.g., couches, gloves, and sharps bins). Additionally, much of the technology used in stress research can be located within these departments (e.g., Blood glucose monitors, BP cuffs, and ECG machines). In terms of environmental stressors, the structure of SBHE departments allow simulation of scenarios that can induce stress in a controlled, scalable manner. Participants can be subjected to stress in a graded way by asking them to complete simulated exercises of increasing difficulty. The difficulty of these exercises may be varied in real-time depending on the performance of the subject – under the guidance of experienced practitioners. One-way mirrors and audiovisual technology, paired with the capacity to collect biochemical, physiological, and psychological data, make SBHE departments an attractive prospect. Stress research does not come void of risk. However, psychological safety is taken seriously by those involved in SBHE. Not only will the protocols surrounding psychological safety pave the way for well-informed, responsible research, but the wealth of experience held by members of faculty will ensure a secure environment for both participants and researchers[81].

Conclusion

The impact of stress within the field of SBHE is multifaceted. Whilst biochemical, physiological, and self-reported metrics may have the potential to identify acute and/or chronic responses to stress, these responses are most likely unique to an individual, leading to foreseeable issues in generalising research findings to a population. However, a combination of stress detection metrics, building on the framework of the allostatic load model, may allow a more comprehensive

view of the stress response. If such a model were integrated with stress intervention techniques, it may enhance an educators' ability to identify individual, simulation-related stress responses that could negatively affect learning and performance, affording 'simulationists' the option of creating an educational landscape conducive to learning. Researchers interested in the human stress response and its impact on performance may find SBHE to be an excellent platform for further studies in this complex area. Some of the authors of this paper have planned a study to investigate the feasibility of conducting stress-related research in a SBHE environment [82], and we hope that further work in this field will lead to enhanced outcomes for learners and a better understanding of the human stress response.

List of abbreviations

In order they appear in manuscript

SBHE: Simulation-based healthcare education

GAS: General adaption syndrome

SAM: Sympathetic-adrenal-medullary

HPA: Hypothalamic-pituitary-adrenal

cAMP: Cyclic adenosine monophosphate

CRH: Corticotropin-releasing hormone

ACTH: Adrenocorticotropic hormone

PSS: Perceived stress scale

STAI: State-trait anxiety inventory

DHEA: Dehydroepiandrosterone

SαA: Salivary alpha amylase

ANS: Autonomic nervous system

BP: Blood pressure

SBP: Systolic blood pressure

DBP: Diastolic blood pressure

HR: Heart rate

ECG: Electrocardiogram

HRV: Heart rate variability

ULF: Ultra low frequency

VLF: Very low frequency

LF: Low frequency

HF: High frequency

IBI: Inter-beat interval

SDNN: Standard deviation of normal-to-normal intervals

RMSSD: Root mean square of consecutive normal-to-normal differences

GSR: Galvanic skin response

SCL: Skin conductance level

SCR: Skin conductance response

HS: High stress

LS: Low stress

OSCE: Objective structured clinical examination

Declarations

Ethics approval and consent to participate

N/A

Consent for publication

N/A

Availability of data and materials

N/A

Competing interests

N/A

Funding

Partly funded by the Northern Ireland Department for the Economy studentship program.

Authors' contributions

Aaron Vage: Designed and developed review from inception to completion. Analysed all literature, major contributor in writing manuscript.

Andrew Spence: Contributor in writing manuscript.

Gerry Gormley: Contributor in writing manuscript.

Gary McKeown: Contributor in writing manuscript.

Paul Murphy: Contributor in writing manuscript.

Paul Hamilton: Major contributor in writing manuscript.

All authors read and approved the final manuscript.

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