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Title: To err again is human: Exploring a bidirectional relationship between pressure and performance failure feedback

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Abstract

Background and Objectives: While the potentially negative effects of pressure on skilled performance have been well studied in laboratory-based research, theoretically driven questions based on real-world performance data are lacking. **Design**: We aimed to test the predictions of the newly developed Attentional Control Theory: Sport (ACTS), using archived play-by-play data from the past seven seasons of the National Football League (American Football). **Methods**: An additive scoring system was developed to characterize the degree of pressure on 212,356 individual offensive plays and a Bayesian regression model was used to test the relationship between performance, pressure and preceding negative outcomes, as outlined in ACTS. **Results**: There was found to be a clear increase in the incidence of failures on high pressure plays (odds ratio = 1.20), and on plays immediately following a previous play failure (odds ratio = 1.09). Additionally, a combined interactive effect of previous failure *and* pressure indicated that the feedback effect of negative outcomes was greater when pressure was already high (odds ratio = 1.10), in line with the predictions of ACTS. **Conclusions:** These findings reveal the importance of exploring momentary changes in pressure in real-world sport settings, and the role of failure feedback in influencing the pressure-performance relationship.

***Keywords*;** anxiety; sport; choking; errors; clutch; dependence

To err again is human: Exploring the interacting effects of pressure and failure feedback on performance.

Introduction

Sport provides an almost perfect environment for examining performance under pressure. Skills that have been honed and perfected during practice can break down just when the need to execute them is greatest. In studying this paradoxical effect, Baumeister (1984) defined pressure as 'any factor or combination of factors that increases the importance of performing well' (pp. 610). The proposed mechanism by which pressure exerts its effect on skilled performance is via increased anxiety, an emotional response to threat, comprising cognitive worry and physiological arousal (Eysenck, 1992). While individual differences in response to pressure do exist (e.g., 'clutch' performance; see Otten, 2009), a large literature base has revealed that anxiety can have deleterious effects on sporting performance by disrupting attention (see Payne, Wilson, & Vine, 2018 for a recent systematic review). There is strong support for the role of attentional disruptions in leading to both increased self-monitoring and control (Baumeister, 1984; Beilock & Carr, 2001; Masters & Maxwell, 2008) and/or increased distractibility (Eysenck, Derakshan, Santos, & Calvo, 2007; Wilson, 2008), but what is less well understood is how and why competitive pressure leads to anxiety in the first instance. A new theoretical development, Attentional Control Theory: Sport (ACTS; Eysenck & Wilson, 2016) seeks to address just this question.

ACTS was developed to extend the predictions of Attention Control Theory (ACT; Eysenck et al., 2007), to the effects of pressure on the relatively automated skills of sport performers. ACT suggests that anxiety leads to an imbalance between goal-directed and stimulus-driven attentional systems, creating increased attention to threat related cues and processing inefficiency. As a result, performance may suffer when compensatory strategies (e.g., increased effort) are unsuccessful (see Eysenck & Wilson, 2016, and Wilson, 2012 for reviews in sporting tasks). While the relationship between anxiety, attention and performance remains as previously outlined in ACT, it is the antecedents of anxiety that receive more attention in ACTS. Specifically, ACTS suggests that a bidirectional relationship exists between pressure and performance, based on feedback loops relating current, to desired performance (Eysenck & Wilson, 2016). It is the outcome of these feedback loops that influences perceptions of threat, which in turn leads to the experience of anxiety (see Figure 1).

This effect is operationalized in ACTS in terms of Berenbaum's two-phase model of worry, which suggests that the initiation of anxiety (specifically its cognitive component worry) is influenced by the perceived *costs* and perceived *probability* of future undesirable outcomes (Berenbaum, 2010; Berenbaum, Thompson, & Pomerantz, 2007). First, undesirable outcomes (e.g., losing, or individual examples of skill failure) are prominent in sporting contexts and the costs of these are greater in high-pressure situations than low-pressure ones, because more is at stake (Baumeister, 1984). However, the experience of pressure is rarely constant, and will depend on momentary reflections on exactly what is at stake. Second, it is likely that the perceived probability of losing increases as a function of the number of failure experiences during a match or competition and decreases as a function of the number of success experiences. Indeed, a qualitative study of young, international golfers by Nicholls, Holt, Polman, and James (2005) identified that three quarters of all stressors could be grouped under themes related to either their own mental and physical errors or good performance from opponents. Such negative performance feedback will increase the perceived probability of subsequent errors if an individual believes that performance exhibits *dependence.*

Dependence reflects the belief that the probability of success on one play is influenced by previous plays and is most frequently associated with research examining performance streaks; colloquially referred to as the hot hand effect (e.g., Bar-Eli, Avugos, & Raab, 2006; Wetzels et al., 2016). However, interpreting negative performance feedback (e.g., an error) as evidence that more mistakes are likely, would also reflect dependence (e.g., Link & Wenninger, 2019). To summarize, ACTS predicts that when both the perceived cost of failure (influenced by fluctuations in the current level of pressure) and perceived probability of failure (influenced by previous unsuccessful performance feedback) are high, the interactive effect will lead to heightened anxiety, impaired attentional control and negative consequences for performance (as summarized in Figure 1).

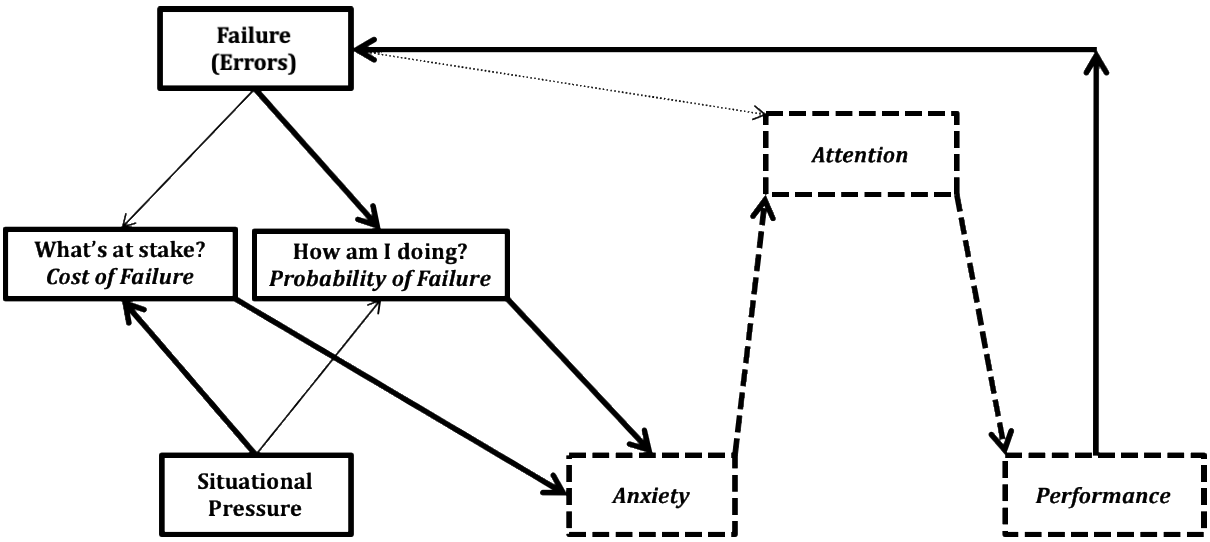

Figure 1. Schematic representation of the bi-directional pressure-performance relationship, as outlined in Attentional Control Theory (Eysenck et al., 2007; dashed lines) and Attentional Control Theory: Sport (Eysenck & Wilson, 2016; solid lines). Of particular importance is the fact that situational pressure does not necessarily result in increased anxiety, but that this is influenced by an individual's perception of the associated costs of failure (primarily influenced by the interpretation of momentary situational pressure) and probability of failure (primarily influenced by the interpretation of preceding errors / negative performance feedback). An additional feedback loop between prior failure and attention reflects the direct influence that error monitoring has on attention.

The current study sought to provide the first test of the basic performance effects proposed in ACTS; by examining the potential interacting effects of preceding failure and situational pressure on subsequent performance. The study sought to develop new knowledge in two ways. First, while it is widely acknowledged that pressure can disrupt performance in many perceptual-cognitive tasks (Payne et al., 2018), there is limited empirical evidence from real-world environments, where pressure will fluctuate from moment to moment (e.g., Deutscher et al., 2018). Second, and as outlined explicitly in ACTS, the pressure-performance relationship is likely to be more complex than the unidirectional effect addressed by the blocked (low pressure vs high pressure) laboratory experimental manipulations adopted in the vast majority of research examining sporting performance under pressure (Eysenck & Wilson, 2016).

To explore the interacting effects of performance dependence and within game fluctuations in pressure in a real-world environment (American Football), we examined every individual play from all games in the National Football League from 2009 to 2016. As it was not possible to test the mediating interpretive processes leading to anxiety (Berenbaum, 2010), we restricted our focus to the proposed relationship between the two input variables (momentary pressure and failure feedback) and the output variable (current performance; see Figure 1). Based on the predictions of ACTS, it was hypothesised that there would be: (i) an increased probability of play failure on high pressure plays; (ii) an increased probability of one play failure following another (i.e. dependence); and (iii) an additional interactive effect, such that the negative effect of negative performance feedback would be exacerbated when pressure is already high (Eysenck & Wilson, 2016).

Methods

Every play from 2009 to 2016 in the National Football League was obtained from www.NFL.com using the R package 'nflscrapR' (Horowitz & Yurko, 2016). This data set provided 362,448 individual plays outlining each play outcome, and game information such as field position (yards from the opposing team's in-goal area), game time remaining, and current score. The discrete nature of American Football plays allows each instance to have a relatively clear positive/negative outcome, while retaining relevance to previous plays (across the four 'downs' – the available attempts to move the ball forward 10 yards before possession is turned over). In order to assess dependence of performance failure, only passing and running plays were analyzed, as kicking plays end a possession.

Performance failure. The analysis focused on play outcomes in relation to the team in possession, such that losing the ball or failing to make ground were negative outcomes or examples of performance failure. Specifically, these outcomes were operationally defined based on agreement between six University level American Football coaches, as plays resulting in: an incomplete pass (including interceptions); a sack (quarterback tackle behind the line of scrimmage); a fumble (player in possession loses control of the ball); or making negative yards (receiver tackled behind line of scrimmage – the imaginary line separating the teams before each play). Finally, plays immediately preceded by a failed play *in the same drive* were then coded as 'post-failure' plays.

Pressure. The occurrence of pressure was inferred based on match conditions that increased the importance of performing well (Baumeister, 1984) and the cost of failure (Berenbaum et al., 2007). The scoring system for the factors that increase pressure was developed based on: (1) previous literature examining performance pressure; (2) discussions with the same six American Football coaches; and (3) agreement between three of the authors. Pressure was predicted to be greater when: the game was close (e.g., Deutscher et al., 2018; Toma, 2017); there was less time remaining (Cao, Price & Stone, 2011; Solomonov, Avugos, & Bar-Eli, 2015; Toma, 2017); an error would confer a greater cost (Berenbaum et al., 2007; Hickman & Metz, 2015); or the expectation of a score was higher (Solomonov et al., 2015). Therefore, a pressure score was assigned in a cumulative manner, based on whether: i) the play was 3rd or 4th down; ii) the game score was close (within 8 points, i.e. a touchdown and 2-point conversion); iii) it was the final quarter; iv) the team in possession was behind; v) the play began in the 'red zone' (i.e. within 20 yards of the in-goal area). This resulted in a 6-point pressure score ranging from 0 (low pressure) to 5 (high pressure).

Data Analysis

Data analysis was conducted in RStudio 1.0.143 (R Core Team, 2017). Twenty-six plays with missing data were removed, and only plays where dependence could be assessed were included (i.e. not the first play in a drive), resulting in 212,356 plays for analysis. A logistic regression model was used to examine the effect of scored pressure and prior failure on subsequent performance (binary outcome), using a Bayesian estimation approach. Bayesian estimation attempts to identify the credible interval of a parameter (Kruschke, 2014) and is particularly appropriate for large data sets, where the impact of sample size on *p*-values makes an examination of significance levels relatively uninformative (Royall, 1986). A Bayesian approach was chosen because it also provides a more intuitive approach to estimating parameters and avoids binary decision criteria (see Kruschke, 2010, for discussion).

Data were modelled as deriving from a Bernoulli distribution, with a logistic link function; $\gamma = Bernoulli(\mu)$ with $\mu = logistic(\beta_0 + \beta_1 + \beta_2 + \beta_3)$. Priors on β were set as a conventional non-informative normal distribution (Kruschke, 2014). Markov Chain Monte Carlo simulations were run using JAGS (Plummer, 2003) based on 50,000 steps. Chain diagnostics indicated good convergence, and effective sample sizes exceeded 17,000. The reliability of observed effects was interpreted based on the credible intervals of the regression coefficients, provided by the posterior distributions (i.e., do the highest density intervals cross zero?). An odds ratio (OR) was also calculated as an unstandardized effect size. All our data, analysis code for NFL plays, Bayesian modelling code and model checking statistics are available from the Open Science Framework (osf.io/mjf5p/).

Results

The regression model indicated that increasing pressure score was a reliable predictor of performance failure (Table 1). The highest density interval (HDI) of the posterior distribution (Figure 2) represents the credible interval of a parameter, and indicates the presence of a reliable effect when the credible values do not cross zero. The estimated pressure effect was modelled within a narrow interval that did not cross zero (β=0.18, 95%HDI [0.17, 0.19]), signifying a reliable effect. The computed OR indicates that a one unit increase in the pressure score, entering the final quarter for example, made an offensive play failure 1.2 times more likely. Prior negative performance feedback also showed a non-zero effect (β=0.09, 95%HDI [0.04, 0.13]), with the OR indicating that a failure on the preceding play increased the chance of a further failure by 1.09 times. Additionally, an interaction effect (β=0.09, 95%HDI [0.07, 0.12]) explained further variance in play success, such that the effect of a one unit increase in the pressure score was 1.1 times greater when the play was also preceded by a play failure[1].

Table 1. Summary of estimated regression coefficients (and their 95% HDI) of predictors in the regression model.

Model				
Predictor	**β**	**HDI low**	**HDI high**	**OR**
Constant	-1.16	-1.19	-1.14	0.31
Pressure	0.18	0.17	0.19	1.20
Post failure	0.09	0.04	0.13	1.09
Interaction	0.09	0.07	0.12	1.10

HDI=Highest density interval, OR=odds ratio

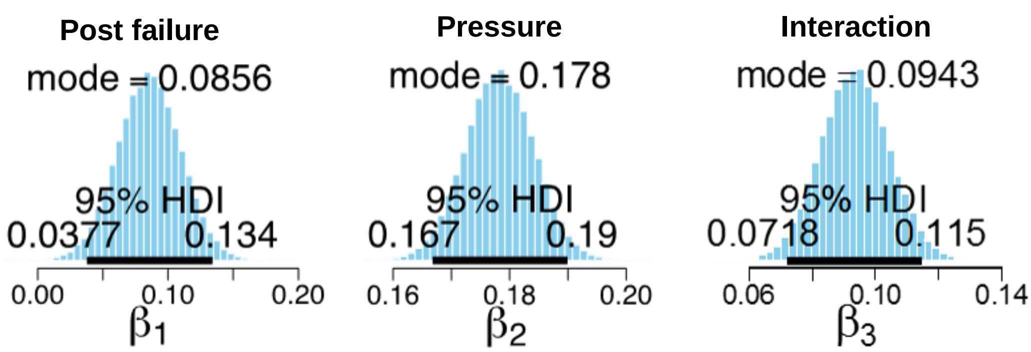

Figure 2. Posterior distributions of regression coefficients, with 95% highest density intervals (HDIs), based on 50,000 steps. These distribution plots indicate that the credible values of the regression coefficients (i.e. the HDIs, resulting from the Markov Chain Monte Carlo simulations) do not include zero.

To further illustrate the interactive effect of pressure score and negative performance feedback, Figure 3 shows the mean rate of failure (with Bayesian credible interval) across the six levels of pressure score, for plays following either a failure or a successful play. The interactive effect

1. Note, a frequentist approach, using a logistic regression gave almost identical regression coefficients and indicated all effects to be significant at *p*<.001.

is evident in the increasing difference between post-failure and post-success plays across increasing pressure scores.

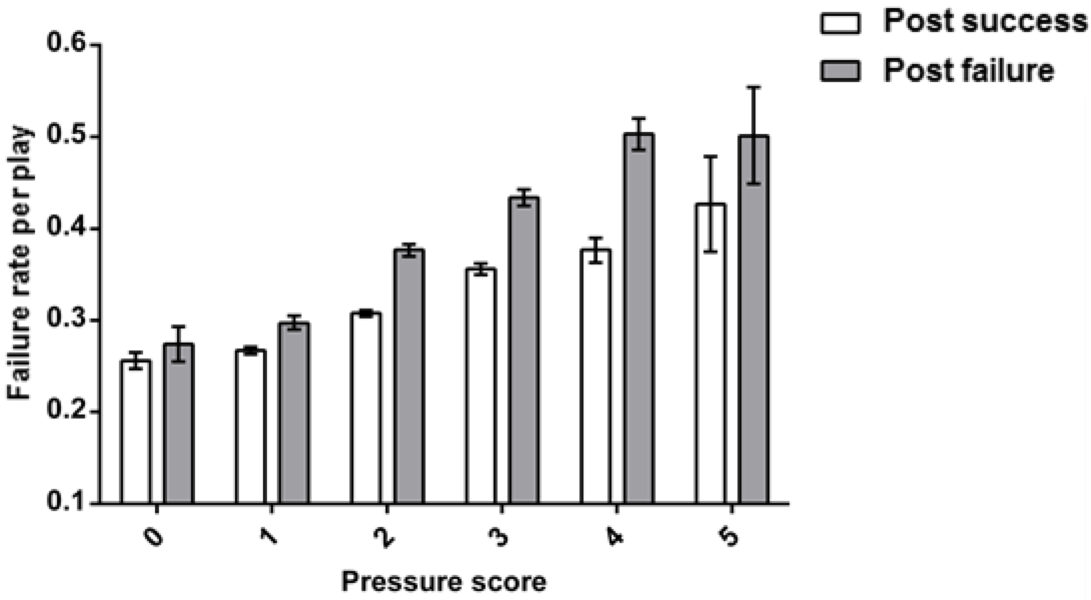

Figure 3. Mean play failure rate (with Bayesian 95% credible intervals) on plays immediately following failed or successful plays, across increasing pressure scores.

To assess the effect of our scoring assumptions for pressure on these outcomes, a robustness analysis (see Willink, 2008) was run by varying the scoring parameters. Assumptions such as closeness of the game (4, 6, 10 or 12 points), distance from the end zone (10, 15, 25 or 30 yards) and number of downs (3rd or 4th) were varied, and other predictors ('last quarter' and 'in the red zone') were removed from the model. Results showed that slight variations to the assumptions had little impact on the results and no effect on conclusions drawn (see supplementary materials for details of these analyses: osf.io/mjf5p/).

Discussion

Despite the pressure-performance relationship being one of the most studied areas in sport psychology, there is limited research that manages to both extend theoretical development and move beyond the artificial confines of the laboratory. This study explored the relationship between momentary pressure and performance dependence in an extensive, detailed, play-by-play data set from elite sport. This is also the first study to explicitly test the main tenets of ACTS (Eysenck & Wilson, 2016), a recent, sport-specific development of one of the most well-researched theories for explaining how anxiety influences performance (ACT; Eysenck et al., 2007). Our three hypotheses – based on the pressure-performance feedback effect outlined in ACTS – were supported, providing key implications for both future research and practice.

First, an unsuccessful offensive play was more likely when the game situation dictated increased pressure (e.g., the game was close, it was the final quarter, and the end zone was near). This finding supports and extends earlier work in basketball by Cao et al. (2011), who found that, compared to career averages, NBA free-throw shooting accuracy was significantly impaired during the final seconds of close games. As such, the pressure-performance effect found here provides further compelling evidence that detrimental effects can be observed in real-world elite sport, and not just in the laboratory. While there were of course instances of successful offensive plays under pressure in this data set (i.e. clutch performance; Otten, 2009), the strength of this analysis of more than 200,000 plays was that the average effect was one of performance impairment (i.e. choking; Baumeister, 1984; Beilock & Carr, 2001).

In line with our second hypothesis, the likelihood of an unsuccessful play was increased following an unsuccessful play on the previous play of the drive. This supports the prediction of ACTS that performance exhibits dependence and that errors can have detrimental feedback effects. Generally, the support for dependence when examining 'hot' performance streaks is mixed (Bar-Eli, Avugos & Raab, 2006), however, the current novel question suggests that negative dependence may have an important influence on performance in pressurized environments (see also Gray & Allsop, 2013). Negative feedback (e.g., perceived errors) may provide a stronger input to subsequent performance expectancies than positive feedback (e.g., hot streaks). This interpretation is supported by recent data in volleyball decision making (Link & Wenninger, 2019) and the work of Baumeister and colleagues, who intimated that "bad is stronger than good", as a general principle across a broad range of psychological phenomena (Baumeister, Bratslavsky, Finkenauer, & Vohs, 2001).

Specifically, these authors noted that bad events have longer lasting and more intense consequences than good events and that the effects of good events dissipate more rapidly than those of bad events.

Of particular importance to the predictions of ACTS was support for our third hypothesis, that the combination of an increased pressure score and a previous error would show an interactive effect. The present finding indicates that, not only does prior failure increase the chance of further failure, but this effect is *larger* under increasing levels of situational pressure. Indeed, Figure 3 reveals that at the highest levels of pressure (i.e. a pressure score of 4 or 5) there is a 50% probability that one failure will be followed by another, compared to only a 27% probability at low levels of pressure (i.e. a pressure score of 1). Importantly, ACTS provides an explanation as to why this stark difference in performance might occur, based on Berenbaum's (2010) initiation model of worry. ACTS suggests that increased pressure will increase the perceived *costs* of failure and that negative performance feedback will increase the perceived *probability* of failure. These in turn will result in increased cognitive anxiety, leading to disruptions to attention and subsequent performance as outlined in Figure 1.

It is important to note that in the current study, specific mediating pathways (e.g., anxiety, worry) could not be directly tested, as we were unable to directly assess how players interpreted the failed offensive plays or pressure. However, the pressure scoring system was based on factors that likely increased the importance of performing (Baumeister, 1984) and was shown to be robust to modifications in its assumptions. We can also be confident that sportspeople do interpret negative performance feedback as a key stressor (e.g., Nicholls et al., 2005), although the fact that different players within the team may respond to the same situation differently, provides additional complexity in interpreting performance data from a team sport. Taken together, while important individual differences in interpretation were not measurable, and extraneous factors could not be controlled for (such as the defence trying harder on some plays), an overall relationship was still found for this large data set, which indicates that the predicted interacting effect of pressure and errors on performance held true despite these individual variations.

Further research is therefore needed to assess the potential modulating effect of the underlying psychological factors in domains where skills are performed under pressure (e.g., sport, military, surgery, aviation). This research will need to explore novel experimental approaches so that the online (or at least temporally proximal) measurement of felt pressure during performance can be considered in relation to ongoing performance expectancies – currently a limitation in most experimental work exploring the impact of state anxiety on performance (Eysenck & Wilson, 2016). Two noteworthy examples of experimental studies that could guide future research, were carried out by Gray and Allsop (2013) and Walters-Symons, Wilson, and Vine (2017). Gray and Allsop (2013) found that pressurized performance in a baseball batting task was influenced by previous performance, and could be mediated by changes in attentional focus (as measured by secondary task performance). Walters-Symons et al. (2017) measured objective attentional changes via eye tracking technology in a golf putting task and examined how these measures changed following misses compared to successful attempts. Participants were able to successfully recover from errors (i.e. missed putts) through a refocusing of visual attention, but additional errors were made when attention remained poor. Similar approaches examining moment-to-moment changes in objective performance markers may be required to understand how fluctuations in pressure and negative appraisals may compound errors.

Despite the need for corroborating experimental data, there are a number of implications arising from the findings of this novel study, and the predictions of ACTS in general. First, there may be additional benefits related to the term ‘expertise-induced amnesia’, which is used to describe the automatic and non-conscious nature of skilled performance (Beilock & Carr, 2001). Performers who can forget their mistakes (or good plays from opponents) – especially when pressure is heightened – are less likely to feel anxious and experience the disruption of attentional control associated with choking. It may be that this is a key characteristic of performers who are described as clutch under pressure (Otten, 2009; Solomonov et al., 2015). Second, practitioners seeking to help performers deal more effectively in pressure situations could use ACTS to guide intervening at two stages; first by reducing the likelihood that environmental pressure leads to anxiety, or second, by limiting anxiety-induced impairments to effective attention control.

In the first instance, Berenbaum's two phase model provides a useful structure: anxiety can be limited if performers can reduce the perceived costs of failure, and do not associate mistakes with an increased probability of further mistakes. Both of these strategies would fit within a framework that either sought to maintain a rational interpretation of the competitive environment (e.g., Rational Emotive Behavioral Therapy; Wood, Barker, Turner, & Sheffield, 2018), or one whereby mistakes are accepted in a non-judgmental way (e.g., a Mindfulness-Acceptance-Commitment approach; Moore, 2009). Additionally, according to the model, it is possible intervene at a later stage by limiting the impact of anxiety on attentional control, either by training individuals to maintain their focus on key sources of information while they perform (e.g., quiet eye training; Vine, Moore, & Wilson, 2014), or by training general functions of working memory implicated in attentional control (e.g., Ducrocq, Wilson, Smith, & Derakshan, 2018; Ducrocq, Wilson, Vine, & Derakshan, 2016).

To conclude, situational pressure, performance failure and their interaction were all shown to be reliable predictors of further performance failures, highlighting the importance of fluctuations in pressure over time and the role of dependencies in performance. The current study is the first to test the predictions of ACTS (Eysenck & Wilson, 2016) and reveal why it is important to adopt a more fine-grained approach to studying the fluctuating nature of perceived pressure in real-world settings, where the consequences of failure are meaningful. The combined effect of situational pressure and the interpretation of failure (especially physical or mental errors) may have severe consequences for subsequent performance, and future work should explore why such effects occur and how they can be limited.

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