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A theory of challenge and threat states in athletes: A revised conceptualisation

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13

14 Abstract

15 The Theory of Challenge and Threat States in Athletes (TCTSA) provides a psychophysiological
16 framework for how athletes anticipate motivated performance situations. The purpose of this review is
17 to discuss how research has addressed the 15 predictions made by the TCTSA, to evaluate the
18 mechanisms underpinning the TCTSA in light of the research that has emerged in the last ten years,
19 and to inform a revised TCTSA (TCTSA-R). There was support for many of the 15 predictions in the
20 TCTSA, with two main areas for reflection identified; to understand the physiology of challenge and
21 to re-evaluate the concept of resource appraisals. This re-evaluation informs the TCTSA-R which
22 elucidates the physiological changes, predispositions, and cognitive appraisals that mark challenge and
23 threat states. First, the relative strength of the sympathetic nervous system response is outlined as a
24 determinant of challenge and threat patterns of reactivity and we suggest that oxytocin and
25 neuropeptide Y are also key indicators of an adaptive approach to motivated performance situations
26 and can facilitate a challenge state. Second, although predispositions were acknowledged within the
27 TCTSA, how these may influence challenge and threat states was not specified. In the TCTSA-R it is
28 proposed that one's propensity to appraise stressors as a challenge that most strongly dictates acute
29 cognitive appraisals. Third, in the TCTSA-R a more parsimonious integration of Lazarusian ideas of
30 cognitive appraisal and challenge and threat is proposed. Given that an athlete can make both challenge
31 and threat primary appraisals and can have both high or low resources compared to perceived demands,
32 a 2x2 bifurcation theory of challenge and threat is proposed. This reflects polychotomy of four parts;
33 high challenge, low challenge, low threat, and high threat. For example, in low threat, an athlete can
34 evince a threat state but still perform well so long as they perceive high resources. Consequently, we
35 propose suggestions for research concerning measurement tools and a reconsideration of resources to
36 include social support. Finally, applied recommendations are made based on adjusting demands and
37 enhancing resources.

38

39 **Keywords:** stress, performance, motivation, emotions, biopsychosocial

40 1 Introduction

41 Jessica¹ is standing at the start of an important road race, with an undulating course, the pressure
42 mounting and her heart beating in her throat, she knows that the race will be physically and mentally
43 demanding. Jessica has trained hard for this. Jessica believes that she is capable of pacing herself and
44 feels ready to tackle the hilly course. She strides off rhythmically, able to follow her pre-race plan, deal
45 with unforeseen events and achieve a personal best. In this example, we would consider that Jessica is
46 in a challenge state. To Jessica's left, Sarah stands at the start of the same race. Just like for Jessica,
47 Sarah feels her heart rate increase, and she knows that the race will be demanding and has also trained
48 hard. However, in contrast to Jessica, Sarah does not believe that she is capable of pacing herself and
49 does not feel ready to tackle the hilly course. She strides off enthusiastically but cannot find her rhythm
50 and is unable to follow her pre-race plan. She deals with unforeseen events poorly and gets distracted
51 and completes the race outside of her expected time. In this example, we would consider that Sarah is
52 in a threat state. These examples illustrate that despite both athletes entering a stressful situation, stress
53 is not always harmful (Cox, 1978), and can in fact benefit performance (Jessica) and related well-being
54 outcomes (see also Selye, 1956).

¹ The scenario described in this paragraph is hypothetical and Jessica and Sarah are fictional characters.

55 The idea that stress can be both adaptive and maladaptive for skilled athletic performance is at the core
56 of the Theory of Challenge and Threat States in Athletes (TCTSA (M. Jones, Meijen, McCarthy, &
57 Sheffield, 2009). The TCTSA offers a psychophysiological framework for how athletes anticipate
58 motivated performance situations (i.e., personally relevant events), such as competitions or selection
59 events; based on an athlete's interpretation of the situational demands and their available resources.
60 The TCTSA proposes that athletes can approach performance situations in either a challenge state or a
61 threat state. In anticipation of a motivated performance situation, an athlete who has high self-efficacy,
62 high perceived control, and an approach focus, is likely to experience a challenge state; on the other
63 hand, if an athlete has low self-efficacy, low control, and an avoidance focus, they are likely to
64 experience a threat state. The TCTSA draws on prominent transactional appraisal theories of stress and
65 emotion, such as the biopsychosocial model (BPSM) of challenge and threat (Blascovich & Mendes,
66 2000), and the work of Lazarus and Folkman (1984) and Dienstbier (1989). In developing the TCTSA,
67 M. Jones et al. (2009) aimed to describe the cognitive, affective, and physiological aspects of challenge
68 and threat states along with potential performance consequences. In particular, in the TCTSA a unique
69 combination of psychological constructs interact to determine challenge and threat states. A number of
70 hypotheses are also put forth by Jones et al. including the assertions that high intensity negative
71 emotions can be experienced in a challenge state, but are perceived as facilitative for performance, and
72 that challenge and threat states influence performance through effort, attention, decision-making and
73 physical functioning.

74 **1.1 Justification and aims**

75 Two recent reviews concerning challenge and threat states (Behnke & Kaczmarek, 2018; Hase,
76 O'Brien, Moore, Lee, & Freeman, 2018) have focused on how challenge and threat states influence
77 performance. But the TCTSA makes broader predictions about competitive anticipatory states that go
78 beyond performance outcomes, and therefore, a review of the research that focuses on challenge and
79 threat states in sport more broadly is warranted to help guide future research and practice. Furthermore,
80 considering that the TCTSA was published ten years ago, it is timely to review the research conducted
81 within sport environments and propose refinements to the theory in order advance challenge and threat
82 theory in sport settings. When proposing the TCTSA in 2009, M. Jones et al. focused on explaining
83 why athletes may perceive an upcoming situation as a challenge or a threat, and what informs the
84 perceived availability of resources in a sporting context. One of the primary aims at the time of
85 proposing the theory was to guide applied work, and outline specific predictions that could be tested
86 within a sporting performance context. The present review extends beyond that, and the aim is to re-
87 evaluate the TCTSA, and in light of the evidence that has amassed since the 2009 publication of the
88 TCTSA, to propose a revised theory (TCTSA-Revised[R]). In the TCTSA-R we reconsider the
89 cognitive appraisal network and provide a more detailed portrayal of how athletes can approach
90 motivated performance situations adaptively, in a challenge state. Therefore, the aims of the current
91 paper are fourfold. First, to provide an overview of how the research has addressed the 15 predictions
92 made by the TCTSA. Second, to explain the mechanisms underpinning the TCTSA in light of the
93 research that has emerged in the last ten years. Third, the role of social support and well-being in
94 challenge and threat states is considered. Finally, considering the initial predictions and emerging
95 research we propose the TCTSA-R with guidance for future research and applied work.

96 **2 Overview of Theory of Challenge and Threat States in Athletes**

97 In its original conception, there were four key components of the TCTSA; demand appraisals and
98 motivational states, resource appraisals, physiological responses, and emotional consequences. First,
99 building on the BPSM, for challenge and threat states to occur, the athlete must perceive the demands

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100 of a situation as dangerous (physical and or esteem), uncertain, and requiring of effort (physical and or
101 mental). To clarify, a motivated performance situation, or motivational state, in a sporting context is
102 often considered a situation in which there is pressure on the athlete to perform, and drawing on
103 Lazarus' work (Lazarus, 1999), is usually personally relevant to the athlete. Competitive sporting
104 situations are typically motivational states because they are personally meaningful to the athlete, the
105 outcome is usually unknown before the start (uncertainty), there is a potential for danger (ego could be
106 at stake when an athlete is worried about the outcome), and effort is required to fulfil athletic potential.

107 Second, in the TCTSA it is proposed that resource appraisals comprise three interrelated constructs,
108 namely self-efficacy, perceptions of control, and achievement goals. Self-efficacy is one's belief in
109 their abilities to successfully accomplish a task (Bandura, 1997). Control is closely linked to self-
110 efficacy and includes acceptance and awareness of factors that are within and outside an individual's
111 personal control (M. Jones et al., 2009). Achievement goals are closely linked to an individual's
112 motivation to participate in sport, and in the TCTSA are drawn from a 2X2 achievement goal
113 framework that comprises mastery and performance achievement goals, aligned with either goal
114 approach or goal avoidance (Elliott & McGregor, 2001). The TCTSA outlines that, typically, a
115 challenge state is characterised by high levels of self-efficacy, a high perception of control, and a focus
116 on approach goals, whereas a threat states is proposed to be characterised by low self-efficacy and
117 control, and a focus on avoidance goals (M. Jones et al., 2009). In a challenge state, the perceived
118 resources are sufficient to deal with the demands of the situation, whereas in a threat state the demands
119 outweigh the perceived resources. There is an important distinction to make between the challenge and
120 threat evaluation and Lazarus' conceptualisation. That is, in the original BPSM, and adapted by the
121 TCTSA, challenge and threat states were considered to be the 'end result' of the evaluation of demands
122 and resources (Seery, 2011). This differs from Lazarus' appraisal process where challenge and threat
123 are considered to be a result of primary appraisals, where challenge reflects a potential for gain, and
124 threat reflects a potential for harm. For Lazarus (1999), this primary appraisal is met with secondary
125 appraisal in which coping potential is appraised. The BPSM and TCTSA deviate from the primary and
126 secondary appraisals concepts in favour of demand and resource appraisals in their formulation of
127 challenge and threat. This consideration is important as it informs the two distinct physiological
128 responses that are associated to challenge and threat states whereby sufficient recourse that outweigh
129 demands correspond to distinct physiological responses that signify a challenge state. In contrast,
130 insufficient resources that do not outweigh demands correspond to distinct physiological responses that
131 signify a threat state (see M. Jones & Turner, 2014).

132 Borrowing from the biopsychosocial model of arousal regulation (Blascovich & Mendes, 2000) the
133 TCTSA outlines that the two distinct physiological responses that mark challenge and threat states can
134 be measured using cardiovascular (CV) reactivity patterns indicative of changes in the stress systems
135 (Blascovich, 2008; Dienstbier, 1989). It was proposed that a challenge state is characterised by
136 increased sympathetic-adreno-medullary (SAM) activity accompanied by an increase in catecholamine
137 release, indexed by increased heart rate (HR) and cardiac output (CO), attenuated preejection period
138 (PEP), and decreased total peripheral resistance (TPR). In essence, a challenge state promotes
139 efficiency of energy (glucose) delivery, and use, due to increased blood flow to the brain and muscles,
140 higher blood glucose levels (fuel for the nervous system) and an increase in free fatty acids that can be
141 used by muscles as fuel (e.g., Dienstbier, 1989). Therefore, a challenge state facilitates improved
142 decision making, effective and maintained cognitive function, decreased likelihood of reinvestment,
143 efficient self-regulation, and increased anaerobic power; all of which are likely to lead to successful
144 sports performance (M. Jones et al., 2009). In a threat state it was proposed that increased SAM activity
145 is accompanied by increased pituitary-adreno-cortical (PAC) activity, and subsequent cortisol release.
146 Thus, increased HR and attenuated PEP occurs, but with an increase or stabilisation in TPR, and a

147 small increase or stabilisation in CO. Thus, in a threat state SAM activity is tempered and therefore
148 efficiency of energy use does not occur as blood flow to the brain and muscles is not increased and the
149 mobilisation of usable energy is slower than in a challenge state (e.g., Dienstbier, 1989). Therefore, a
150 threat state leads to ineffective decision making and cognitive function, increased likelihood of
151 reinvestment, inefficient self-regulation, and decreased anaerobic power (compared to a challenge
152 state); all of which are likely to lead to unsuccessful sports performance (M. Jones et al., 2009). In
153 short, in a challenge state, SAM activation is fast-acting and represents the mobilisation of energy for
154 action (fight or flight) and coping. A threat state accompanies slow-acting PAC (and SAM) activation
155 and represents a ‘distress system’ associated with perceptions of actual harm (Blascovich & Tomaka,
156 1996).

157 Finally, the TCTSA also outlined the emotional consequences related to challenge and threat states. In
158 particular, it was suggested that positive emotions are *typically* associated with a challenge state, and
159 negative emotions with a threat state. This is, however, influenced by how facilitative or debilitating a
160 person perceives their emotional state to be, in line with G. Jones’ (1995) model of debilitating and
161 facilitative competitive state anxiety. That is, an athlete can experience anxiety before a competition,
162 but can perceive this anxiety to be facilitative for their performance. Together, challenge and threat
163 states can influence performance through decision-making, cognitive functioning, task engagement,
164 and physical functioning. Typically, it is suggested that a challenge state is beneficial for athletic
165 performance (M. Jones et al., 2009).

166 **3 Review of research of challenge and threat states in sport**

167 Since proposing the TCTSA in 2009, the theory has been referenced across a range of domains besides
168 sport. For example, the TCTSA has been considered in aviation (Vine et al., 2015), surgery (Moore,
169 Vine, Wilson, & Freeman, 2014), sport fans behaviour (Sanderson, 2016), change management in
170 business (Slater, Evans, & Turner, 2016), public speaking tasks (Trotman, Williams, Quinton, &
171 Veldhuijzen van Zanten, 2018) and visual search tasks (Frings, Rycroft, Allen, & Fenn, 2014; Laborde,
172 Lautenbach, & Allen, 2015). In addition, Turner and Barker (2014a) produced a detailed application
173 of the TCTSA in business settings, in which ‘performance’ was considered to be broader than athletic
174 skill execution. Considering that the original focus of the TCTSA was how athletes approach
175 competitive sporting situations, we will only discuss studies that have focused on challenge and threat
176 states in sport settings and or sports-related tasks. In the next section the key findings of studies that
177 have cited the TCTSA and appeared to have tested one or more of the 15 predictions of the TCTSA
178 will be summarised.

179 From the sport-related studies that have cited the TCTSA, or measured challenge and threat states in a
180 sporting context but did not cite the TCTSA, a minority of studies have measured cardiovascular
181 responses. Fine motor skills tasks such as golf putting (Freeman & Rees, 2009; Kingsbury, Gaudreau,
182 Hill, & Coplan, 2014; Moore, Vine, Freeman, & Wilson, 2013; Moore, Wilson, Vine, Coussens, &
183 Freeman, 2013), dart throwing (Moore, Young, Freeman, & Sarkar, 2017), virtual ball task (Huber,
184 Brown, & Sternad, 2016), carom billiard (Corrado, Vitali, Robazza, & Bortoli, 2015), and shooting
185 (Rossato, Uphill, Swain, & Coleman, 2018) were used in the majority of the studies that measured
186 performance as an outcome. Other researchers assessed performance using cricket batting performance
187 (Turner et al., 2013) or soccer match performance (Dixon et al., 2019). Some studies used speech tasks
188 to assess challenge and threat states (Allen, Frings, & Hunter, 2012; Meijen, Jones, Sheffield, &
189 McCarthy, 2014) in a sport sample, whereas other studies employed reflective diaries to ask athletes
190 about their challenge and threat experiences (e.g. Nicholls, Polman, & Levy, 2012) or interviews and
191 observations (Didymus & Fletcher, 2017; Massey, Meyer, & Naylor, 2013).

192 3.1 The predictions of the TCTSA: What do we know now?

193 When the TCTSA was published, 15 predictions were proposed (see Table 1). Typically, in support of
194 prediction 1, studies where cardiovascular responses were measured found that demand appraisals led
195 to an increase in heart rate. In the majority of the studies danger, uncertainty, and effort were
196 manipulated as part of the research design. For example, participants would be asked to perform in
197 front of assessors (Turner, Jones, Sheffield, & Cross, 2012; study 2), were told that they would be
198 compared to others (Brimmell, Parker, Wilson, Vine, & Moore, 2019; Moore, Vine, Wilson, &
199 Freeman, 2012; Moore, Wilson, et al., 2013; Mosley, Laborde, & Kavanagh, 2017; Sammy et al., 2017;
200 Turner et al., 2012), that they would be interviewed if they performed poorly (Brimmell et al., 2019;
201 Moore et al., 2012; Moore, Wilson, et al., 2013), that they would be judged by coaches (Turner et al.,
202 2013), and/or that they would be videotaped (Brimmell et al., 2019; Moore et al., 2012; Mosley et al.,
203 2017; Turner et al., 2012).

204 A majority of the studies appeared to test predictions 2 and 3, examining the associations between self-
205 efficacy, perceptions of control, and achievement goals, using self-report measures or interviews (for
206 example Howle & Eklund, 2013; Meijen, Jones, McCarthy, Sheffield, & Allen, 2013). Meijen et al.
207 (2013) found that avoidance goals were positively related to a threat perception, and approach goals
208 and self-efficacy negatively predicted a threat perception. We also identified that a substantial number
209 of studies explored the relationship between challenge and threat states and emotional responses
210 (predictions 6 and 7). Typically, these studies identified a positive relationship between anxiety and
211 threat states (for example, Williams, Cumming, & Balanos, 2010). Overall, there is mixed evidence to
212 support the proposed relationships between the resource appraisals (self-efficacy, perceptions of
213 control, achievement goals), cardiovascular indices of challenge and threat, and emotions. Some
214 published studies support the proposed relationships (Trotman et al., 2018), whereas others do not
215 (Dixon et al., 2019; Turner et al., 2012; 2013). Indeed, in one study, higher levels of self-efficacy were
216 associated with a threat state, which is contrary to the TCTSA (Meijen et al., 2014). Moreover, Dixon
217 et al. (2019) showed that challenge CV reactivity positively predicted future soccer performance (rated
218 by players and coaches), but that athletes with a blunted CV response performed worse than challenge
219 and threat responders and that there was a weak association between self-report data and cardiovascular
220 responses. Interestingly, the findings of Trotman et al. (2018) show support for the central tenets of the
221 TCTSA during competitive stress, but not social stress. This suggests that the type of task may have
222 an impact on the relationship between resource appraisals and cardiovascular reactivity, and that
223 blunted cardiovascular responses need to be considered (see also Wormwood et al., 2019). Moreover,
224 whereas there is mixed evidence for the link between resource appraisals and physiological responses,
225 there is more consistent evidence that improving resource appraisals benefits a challenge state (e.g.
226 Turner, Jones, Sheffield, Barker, & Coffee, 2014).

227 The TCTSA further predicted (predictions 4 and 5), in line with the BPS model of arousal regulation,
228 that an increase in SAM activation alone as indicated by increased epinephrine and norepinephrine
229 reflects a challenge state. Increased SAM activation combined with PAC activation was suggested to
230 characterise a threat state. No research has assessed the underlying neuroendocrine responses, rather
231 most studies used the challenge and threat index (based on Blascovich, Seery, Mugridge, Norris, &
232 Weisbuch, 2004) to assess the challenge and threat cardiovascular response (Allen et al., 2012; Meijen
233 et al., 2014; Moore et al., 2012; Moore, Wilson, et al., 2013; Sammy et al., 2017; Turner et al., 2012;
234 2013; 2014; Vine, Freeman, Moore, Chandra-Ramanan, & Wilson, 2013) to differentiate between
235 challenge and threat states. This challenge and threat index is calculated by converting the CO and TPR
236 reactivity scores into Z scores and summing them, with CO being assigned a weight of +1 and TPR a
237 weight of -1. High scores indicate a challenge, and low scores a threat. Some of these studies also

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238 reported cardiac output and total peripheral reactivity scores separately (i.e. Meijen et al., 2014; Turner
239 et al., 2012). Although most of the studies identified distinct challenge and threat cardiovascular
240 reactivity patterns (Moore et al., 2012; Sammy et al., 2017; Turner et al., 2014), some studies failed to
241 observe a distinct cardiovascular reactivity pattern (Meijen et al., 2014), and no studies have measured
242 the underlying neuroendocrine responses.

243 The interpretation of emotional states (prediction 8 and 9) was typically assessed by experimental
244 studies focused on reappraising of arousal (Moore, Vine, Wilson, & Freeman, 2015; Sammy et al.,
245 2017). Together they found that re-appraising arousal had the potential to promote a challenge state.
246 Furthermore, Williams et al. (2010) used imagery to manipulate challenge and threat states and found
247 that participants interpreted anxiety as more facilitative during the challenge script.

248 The prediction that there is a need for less self-regulation in a challenge state was predominantly tested
249 in relation to use of coping strategies (Allen et al., 2012; Mosley et al., 2017) (prediction 10). Some
250 support was evident for this prediction, in particular those who responded to a situation as a threat
251 seemed to draw on more problem-oriented and emotion-focused coping (Allen et al., 2012).
252 Furthermore, the presence of a pacer, as a coping strategy, can reduce the required sources and
253 subsequently lead to less need for self-regulation (H. Jones et al., 2016).

254 Prediction 11 and 12 outlines that anxiety decreases the efficiency and effectiveness of cognitive
255 functioning in a threat state (prediction 11), but that in a challenge state anxiety does not lead to
256 reinvestment (prediction 12). Some support was provided for these predictions, Sammy et al. (2017)
257 found that performance did not improve more after arousal reappraisal (which was suggested to
258 promote a challenge state) compared to a control group. They suggested that, in line with attentional
259 control theory (Eysenck, Derakshan, Santos, & Calvo, 2007), participants may have used
260 compensatory strategies such as increased effort to deal with the pressure from the task. Furthermore,
261 after a challenge manipulation, experienced golfers used less conscious processing (Moore, Wilson, et
262 al., 2013). Although Robazza et al. (2018) did not measure cardiovascular reactivity patterns, they did
263 suggest that, for junior orienteers, a worsened psychobiological state (similar to a threat state) together
264 with reduced 'top-down executive functions' seemed to negatively affect performance.

265 Prediction 13 states that athletes engage less in competition when they are in a threat state. That is,
266 athletes draw more on avoidance strategies, and may engage in freezing where they may perceive a
267 demand to be dangerous and therefore disengage themselves from the situation (M. Jones et al., 2009).
268 In practical terms, this may be an athlete who decides to avoid going into a tackle at a rugby match.
269 Although there were no experimental studies focusing on this prediction, Howle and Eklund (2013)
270 found that a challenge state was associated with lower avoidance goals.

271 Prediction 14 of the TCTSA states that being in a challenge state can have a positive influence on
272 decision-making. In one study, there was a positive relationship between threat appraisals and
273 autocratic coaching behaviours (Dixon, Turner, & Gillman, 2017). In addition, although not conducted
274 with an athletic sample, Turner et al. (2012) found that a challenge CV state was related to superior
275 accuracy on the Stroop Test, used to assess decision making.

276 Only one study (Wood, Parker, Freeman, Black, & Moore, 2018) has directly considered the impact of
277 challenge states on anaerobic power (prediction 15). In this study there was a relationship between
278 challenge appraisals and anaerobic power in a cycling task, with challenge appraisals being associated
279 with greater anaerobic power, however, there was no relationship between cardiovascular reactivity
280 and anaerobic power in a cycling task. It was noted by the authors (Wood et al., 2018) that

281 methodological issues, such as the length of time between baseline trials and performance impacted
282 power levels during the test itself and therefore is a need for more research on this prediction. The
283 limited research may not be surprising considering the physiological changes that the body undergoes
284 from rest to vigorous physical activity. The influence of experiencing a challenge state, however, could
285 impact the perceived effort ratings of athletes (H. Jones et al., 2016).

286

287 ---Insert Table 1 around here ---

288

289 Consideration of the sports-related studies that cited the TCTSA or measured challenge and threat
290 states in a sporting context illustrates two main areas for reflection. The first is understanding the
291 physiology of challenge and threat. That is, what are the physiological changes under stress that are
292 reflected in the distinct patterns of cardiovascular reactivity and are there other physiological correlates
293 or determinants of challenge and threat states? The second consideration is that the resource appraisals
294 outlined in the TCTSA need re-evaluating as these do not consistently link to the proposed patterns of
295 CV reactivity. Some of these findings may represent the social desirability inherent in self-report
296 measures (cf. Meijen et al., 2014) or that the tasks used may not approximate sufficiently to competitive
297 situations (cf. Trotman et al., 2018). Nevertheless, the inconsistent findings do require a second look,
298 if not a re-evaluation, and reflection on whether other concepts, such as perceived social support, need
299 to be considered as part of resource appraisals to better represent the social environment inherent to
300 challenge and threat states.

301 **3.2 The physiology of challenge and threat states**

302 The physiological mechanisms underpinning and reflecting a challenge response in athletes was
303 outlined in the BPSM and adapted by the TCTSA. In this section we review the proposals in the TCTSA
304 in more depth and we consider wider physiological markers which underpin, and reflect, challenge and
305 threat states. Based on the work of Blascovich and colleagues (1996; 2000) it was proposed that a
306 challenge state is characterised by activation of the sympathetic nervous system and accompanying
307 increases in epinephrine and norepinephrine, evidenced by an increase in cardiac activity along with a
308 decrease in peripheral vascular resistance. In contrast, a threat state is characterised not only by activity
309 of the sympathetic nervous system, but also increased activity the hypothalamic pituitary adrenal
310 (HPA) axis, accompanying increases in cortisol, smaller increases in cardiac activity and either no
311 change or an increase in peripheral vascular resistance.

312 More recent explanations of the physiological underpinnings of challenge and threat states have
313 focused on the temporal aspects of the sympathetic nervous system (SNS) response, where it was
314 proposed that challenge states result from a quick SNS response which quickly habituates, whereas
315 threat states have a slower rise in SNS activity which tends to stay elevated for a longer time (Epel et
316 al., 2018). It is this response that is reflected in the differing patterns of challenge and threat
317 cardiovascular reactivity. This explanation would fit within the timescales typically used in
318 cardiovascular reactivity research, but again the mechanisms need further elucidating. Specifically, the
319 release of norepinephrine under acute stress leads to vasoconstriction (Carter & Goldstein, 2015).
320 Indeed, one of the criticisms by Wright and Kirby (2003) is that SAM activity is associated with the
321 release of norepinephrine which has vasoconstrictive effects and so even if the release of epinephrine
322 did reduce resistance through dilation any effect could be offset by norepinephrine. To explain the
323 observed vasodilation, we propose that under conditions of challenge SNS activation quickly dissipates

324 (cf. Epel et al., 2018) and it is the decrease in sympathetic stimulation that allows *relative* vasodilation
325 in the arterioles, reflected in decreased vascular resistance. Under conditions of threat, because the SNS
326 activation does not dissipate, this is reflected in continued vasoconstriction (Webb, 2003). This is a
327 testable hypothesis, best examined through manipulating challenge and threat states, although to the
328 best of our knowledge has not been explored. Specifically, minute by minute analyses of individuals
329 displaying challenge and threat cardiovascular reactivity should demonstrate for both groups an
330 increase in vasoconstriction in the immediate seconds after the acute stressor (e.g., 60 seconds).
331 Thereafter the patterns should, however, diverge. Specifically, those who are challenged should show
332 relative vasodilation indicating the absence of sympathetic stimulation, whereas those who are
333 threatened should continue over the next few seconds (e.g., up to 120 seconds) to show vasoconstriction
334 resulting from continued sympathetic stimulation.

335 After the initial few minutes of SNS response to the motivated performance setting there may be further
336 divergence of those exhibiting a challenge and threat response with greater levels of cortisol in those
337 who are threatened. The arousal from HPA activation, which is greater in a threat state, will not
338 dissipate quickly because cortisol has a much longer half-life (30-90 minutes; Kirschbaum &
339 Hellhammer, 1994). In contrast peak catecholamine (epinephrine, norepinephrine) responses should
340 decline only to the level needed to sustain active coping (Dienstbier, 1989) and this may vary
341 depending on the nature and demand of the sport. This is of course a difficult task considering challenge
342 and threat states in athletes given different sports have different demands, and the feasibility of
343 measuring physiological responses immediately before or during sporting performance may not be
344 possible. What this also underlines is that, because the consequences of HPA axis activation are active
345 for that amount of time, there is a stronger link with anticipatory appraisals than retrospective appraisals
346 related to stress (Gaab, Rohleder, Nater, & Ehlert, 2005). Whereas the explanation of challenge and
347 threat states has focused on SNS and HPA activation, the parasympathetic nervous system may also
348 play a role as outlined in this issue with potentially a withdrawal of the parasympathetic system being
349 an indicator of a threat state (see Uphill, Rossato, Swain, & O'Driscoll, 2019 for a detailed discussion).

350 Considering the relevance of anticipatory appraisals for HPA axis activation, this links in well with our
351 second consideration when reflecting on the TCTSA research. The TCTSA outlined specific resource
352 appraisals that inform anticipatory appraisals, the research findings are, however, less consistent with
353 the predictions. One of the potential limitations of how resource appraisals were set out in the TCTSA
354 is that they were focused on individual resources to the neglect of social ones. Social support, however,
355 was a component of resources appraisals described by Lazarus and Folkman (1975), and the
356 importance of social environments in determining cardiovascular reactivity and performance have long
357 been recognised (Carroll & Sheffield, 1998; Uchino, Carlisle, Birmingham, & Vaughn, 2011). This
358 consideration is relevant, as aspects such as perceived social support can influence anticipatory
359 appraisals and anticipatory BP and haemodynamic responses to mental stress (Gramer & Reitbauer,
360 2010). To elaborate, although the TCTSA borrows from the biopsychosocial model of arousal
361 regulation (Blascovich & Mendes, 2000), the TCTSA did not make specific predictions about the role
362 of perceived social support. In addition, Dixon et al. (2017) found that coaches who appraised a stressor
363 as a challenge were more likely to provide social support to their athletes. We propose that both the
364 perception and provision of social support plays an important part as a resource in anticipation of a
365 motivated performance setting (Kirsch & Lehman, 2015), which can influence oxytocin levels
366 (Heinrichs et al., 2003). Therefore, we will now focus on a brief overview of perceived social support,
367 and how we see it fit in relation to challenge and threat states.

368 **3.3 Social support in challenge and threat research**

369 Social support involves ‘an exchange of resources between at least two individuals perceived by the
370 provider or recipient to be intended to enhance the well-being of the recipient’ (Shumaker & Brownell,
371 1984, p. 13). It benefits self-confidence (Freeman & Rees, 2010), motivation, performance (Freeman
372 & Rees, 2009; Tamminen, Sabiston, & Crocker, 2019), well-being (DeFreese & Smith, 2014), group
373 cohesion, performance slumps and injury recovery (Madden, Kirkby, & McDonald, 1989; Udry, 1996)
374 and competitive and personal stressors (Crocker, 1992; Rees & Hardy, 2000) as a situational
375 characteristic implicit in the competitive stress process.

376 Though social support includes functional (i.e. support exchanges), structural (i.e. support network),
377 and perceptual (i.e. support appraisal) aspects (Bianco & Eklund, 2001), sport researchers focused
378 upon functional aspects (Arnold, Edwards & Rees, 2018) and perceived availability of support and
379 support received (Freeman & Rees, 2010). Perceived support comprises four dimensions (i.e.,
380 emotional, esteem, informational and tangible) and matters more to outcome variables such as
381 performance and self-confidence than support actually received.

382 Research shows that social support influences outcomes directly (i.e., main effects model) or
383 indirectly (i.e., stress buffering hypothesis). In the main effects model, researchers identified the
384 association between social support and performance factors in tennis (Rees, Ingledew, & Hardy,
385 1996; Rees & Hardy, 2004) and performance outcomes in golf (Rees & Freeman, 2009; Rees, Hardy,
386 & Freeman, 2007). According to the stress buffering hypothesis, social support can moderate the
387 effects of stressors on outcomes. Perceived social support aids the appraisal process by redefining the
388 situational threat and augmenting the individual’s perceived control and ability to cope. Together,
389 such resources increase coping behaviours, self-efficacy with concomitant changes in the affective,
390 physiological and behavioural response to stress (Arnold et al., 2018; Cohen, Gottlieb, &
391 Underwood, 2000; Freeman & Rees, 2009, 2010; Rees & Freeman, 2009; Rees & Hardy, 2004).

392 The collected research holds that social support benefits psychological well-being and sport
393 performance though researchers sometimes overlook the social constituent of the biopsychosocial
394 trinity in the BPSM. Blascovich (2008) proposed social support to influence demand and/or resource
395 evaluations; however, previous research examining the effect of perceived social support on
396 cardiovascular reactivity to stress offered equivocal results (see O’Donovan & Hughes, 2008; Closa
397 León, Nouwen, & Sheffield, 2007). Moore, Vine, Wilson, and Freeman (2014) reported that
398 perceptions of support availability had no significant influence on participants’ demand/resources
399 evaluations, cardiovascular responses or performance in a laparoscopic surgery task.

400 Perceived social support helps the athlete in motivated performance situations. Although self-relevant
401 goals like a monetary reward might be important, one’s basic need to form and maintain social bonds
402 (e.g., Baumeister & Leary, 1995) means that making a good impression (e.g., on the experimenter)
403 might be a typical source of motivated performance in a laboratory setting (Seery, 2013). In
404 ecologically diverse settings, the presence of others (e.g., social anxiety, social comparison, social
405 power) primes a psychological response that could be mediated by the perceived social support of
406 teammates, coaches, family, and friends allowing athletes to locate resources to marshal the stressors
407 encountered in motivation performance situations. Dixon et al. (2017) explored the relationships
408 between challenge and threat cognitive appraisals and coaching behaviours in football coaches. Their
409 results suggested that coaches with a tendency to appraise a stressor as a challenge are more likely to
410 offer social support to their athletes. A series of stress reappraisal interventions (Jamieson, Mendes,
411 Blackstock, & Schmader, 2010; Jamieson, Nock, & Mendes, 2013) demonstrated better performance
412 outcomes and diminished stress responses in participants who received the reappraisal instructions.

413 Clearly, psychosocial factors such as perceived social support can influence the cognitive appraisal
414 process. Not only can perceived social support provide a stress buffer, Slater, Evans, and Turner
415 (2016) propose that social support could influence the perception of demand and resource appraisals.
416 For example, an athlete who perceived high availability of social support may reasonably appraise
417 less required effort due to shared problem solving, and less danger to esteem through the knowledge
418 that no matter what happens (e.g. failure) they will be safe in their social group. For the resources,
419 research has demonstrated how instructional sets that promote perceptions of high resources can lead
420 to a challenge state (Turner et al., 2014), and this has clear ramifications for social support,
421 particularly informational support. In anticipation of a competition, a number of people surrounding
422 an athlete can provide information that could increase (and of course decrease) the athlete's
423 perceptions of self-efficacy, control, and goal orientation. A coach could encourage the athlete to
424 reflect on successful performances in the past (self-efficacy); a teammate could orient the athlete
425 towards aspects of the performance that they can control such as sticking to the game plan, or
426 preparing in the right way (control); a friend could encourage the athlete to focus on the opportunity
427 they have to demonstrate their many skills and abilities (approach goals). The role of the coach in
428 athlete challenge and threat states is potentially important. Research (Slater, Turner, Evans, & Jones,
429 2018) indicates that performers who perceive high connectedness (high relational identification) with
430 a task leader report greater resource appraisals and performed better (in a cognitive task). Slater et al.
431 also found that being led by an individual with whom participants felt low connectedness (low
432 relational identification) elicited threat CV reactivity to a pressurized task (Study 3). It is important
433 that athletes perceive that these support options are available, from people with whom they share a
434 strong connection, and that they seek to use these opportunities for social support in anticipation of a
435 motivated performance situation.

436 **4 Revising the Theory of Challenge and Threat States in Athletes**

437 Thus far we have set out the initial predictions of the TCTSA, reviewed research that has directly or
438 indirectly tested predictions that were proposed when introducing the TCTSA, we have critically
439 reviewed the physiological aspects and resources, and explained the relevance of adding perceived
440 social support to the TCTSA as a resource appraisal. The story is complex, and with the TCTSA-R we
441 are cautious not to oversimplify the complexity of the human anticipatory responses that are at the core
442 of the TCTSA. Nevertheless, we endeavour to clarify aspects of the TCTSA and make updated
443 suggestions that we hope will stimulate debate and further (applied) research in relation to stress and
444 athletic performance. The focus points of the TCTSA-R are: physiological changes, predispositions,
445 and cognitive appraisal.

446 **4.1 Physiological changes**

447 The relative patterns of norepinephrine, epinephrine, and cortisol reflect responses to an acute stressor
448 and underlying appraisals and are manifested in specific patterns of cardiovascular reactivity as
449 outlined in the BPSM. The explanation that cardiovascular (CV) predictions derive from SAM and
450 HPA activation has, however, been debated (Blascovich et al., 2003; Wright & Kirby, 2003). One
451 criticism is that HPA axis activity is not sufficiently quick to be reflected in immediate CV reactivity.
452 Indeed, the methodologies used to identify patterns of cardiovascular reactivity indicative of challenge
453 and threat states show changes in a few minutes from baseline. Typically, studies have assessed and
454 accordingly, found challenge and threat states in the first minute (e.g., Blascovich et al., 2004; Meijen
455 et al., 2014; Moore et al., 2012), two minutes (e.g., Allen et al., 2012; Blascovich et al., 2004) three
456 minutes (e.g., Mendes et al., 2003; Turner et al; 2012; Turner et al., 2013; Turner et al 2014, study 2)
457 or four minutes (e.g., Turner et al., 2014, study 1) following the onset of the stressors. This time frame

458 is likely too short for CV reactivity to be influenced by HPA axis activity (Herman et al., 2016). Of
459 course, this does not mean that HPA axis activity is not important in underpinning challenge and threat
460 states, and HPA axis activity may differ across challenge and threat states. Rather, it means that the
461 CV reactivity observed in the overwhelming majority of studies in which challenge and threat have
462 been explored is not likely to have been influenced by HPA activity. In our revised TCTSA-R we
463 propose that oxytocin and neuropeptide Y are also both key indicators of an adaptive approach to
464 motivated performance situations and differing levels can be reflected in challenge and threat states.

465 Neuropeptide Y (NPY) is a 36 amino acid peptide, and receptors for NPY are associated with three
466 key locations in the brain that deal with stress: the amygdala, the hippocampus, and the locus coeruleus
467 (Nulk, Schuh, Burrell, & Matthews, 2011). An increased level of NPY in the amygdala are associated
468 with decreased feelings of anxiety, and increased levels generally may decrease the rate of locus
469 coeruleus firing, resulting in lower levels of NE in the brain (Nulk et al., 2011). These propositions are
470 supported by research in performance environments. Under acute stress increases in norepinephrine
471 and cortisol were significantly and positively associated with increases in plasma levels of NPY in
472 military personnel, including Special Forces personnel in the US (Morgan et al., 2000, 2001, 2002).
473 The data from Morgan and colleagues suggest that levels of NPY are significantly and negatively
474 associated with the subjective reports of stress. NPY has a counterbalancing effect to Corticotropin-
475 releasing hormone (CRH) and the balance between these two biochemicals is key, with CRH needed
476 to maintain the stress response, while NPY is needed to counteract long term damage caused by
477 prolonged stress (Nulk et al., 2011). It was also suggested by Morgan and colleagues that a rise in
478 peripheral plasma NPY (which was what was assessed in the military studies by Morgan and
479 colleagues) may in itself exert central effects as peripheral infusion of NPY has been showing to have
480 a central effect of decreasing HPA axis activation (cf. Antonijevic et al., 2000). In short, NPY seems
481 to moderate the stress response allowing a helpful, rather than unhelpful stress response.

482 A second biochemical that may play this role of moderating the stress response is oxytocin. Oxytocin
483 is a neuropeptide produced in the hypothalamus that plays an important role in prosocial behaviours
484 (Heinrichs, Baumgartner, Kirschbaum, & Ehlert, 2003). There is consistent evidence that oxytocin is
485 associated with lower levels of cortisol under acute stress (e.g., Cardoso, Ellenbogen, Orlando, Bacon,
486 & Jooper, 2013; Ditzen et al., 2009; Linnen, Ellenbogen, Cardoso, & Jooper, 2012; Robyn et al., 2016).
487 The dampening effect of oxytocin on cortisol may, however, only occur in tasks that are sufficiently
488 stressful to elicit a strong HPA-axis response (Cardoso, Kingdon, & Ellenbogen, 2014). This is
489 important in athletic samples because oxytocin rises in response to perceived social support (e.g.,
490 Kubzanskya, Mendes, Appleton, Block, & Adler, 2012; McQuaid et al., 2016) and so the provision of
491 support by significant others, coaches, team-mates, audiences may be an important factor in facilitating
492 challenge states (Turner & Barker, 2014b). Indeed, there is evidence that under a stressful speech and
493 mathematics task participants who were given oxytocin, compared to placebo participants, exhibited a
494 trend (albeit non-significant) toward greater increases in CO indicating greater SNS activation in those
495 with higher levels of oxytocin. The mechanism by which oxytocin would impact SNS activation does
496 need elucidating, however there does seem preliminary evidence at least, certainly around HPA
497 activation, that oxytocin may be an important factor in determining a challenge response.

498 **4.2 Predispositions**

499 At its inception, it was acknowledged within the TCTSA that predisposition aspects including
500 perfectionism, optimism, and hardiness influence challenge and threat states. We did, however, not
501 specify the direction of how these dispositional factors influence challenge and threat states as our

502 intention was so focus on the dynamicity of the state responses. In the revised theory, we provide some
503 greater clarity how dispositional style relate to challenge and threat states.

504 The notion that predispositions are an important part of cognitive appraisal is not new. In his early
505 works, Lazarus recognised that the extent to which a situation is appraised as stressful or not can be
506 influenced by dispositions (e.g., disposition to deny threat; Speisman, Lazarus, Mordkoff, & Davison,
507 1964). There is a vast array of predispositional factors that could influence cognitive appraisals ranging
508 from genetics, to personality characteristics. A more promising predisposition that is nested within
509 challenge and threat theory is the notion of trait challenge and threat. Contemporary research with elite
510 rowers (Cumming, Turner, & Jones, 2017) shows that predisposed cognitive appraisal style is
511 associated with, and further predicts, subsequent state cognitive appraisals. Specifically, predisposed
512 challenge was associated with event-specific state challenge, and predisposed threat was associated
513 with event-specific state threat, on approach to subsequent motivated performance situations. This
514 evidence from elite sport supports previous research (Skinner & Brewer, 2002) that also found that
515 predisposed cognitive appraisal style can predict subsequent cognitive appraisals. There is also some
516 evidence that irrational beliefs, as proposed with rational emotive behaviour therapy (REBT), form an
517 important part of the cognitive appraisal network (e.g., David, Schnur, & Belloiu, 2002), and that
518 higher irrational beliefs are related to greater threat (Dixon et al., 2017; Evans et al., 2018). For
519 example, in a recent study in this issue, golfers approaching a motivated performance situation with
520 high irrational beliefs were more likely to evaluate the upcoming competition as a threat (Chadha,
521 Turner, & Slater, 2019). In line with TCTSA postulations, greater threat was related to greater negative
522 emotion, greater competitive anxiety, and a less facilitative interpretation of anxiety. Irrational beliefs
523 are considered to be ‘deep’ cognitions akin to schemas or core beliefs, which are consider to be trait-
524 like or dispositional (Turner, 2016). Thus, we argue that although a complex constellation of
525 predispositional factors could influence acute cognitive appraisal, it is perhaps one’s propensity to hold
526 irrational core beliefs and one’s proclivity to appraise stressors as a challenge that most powerfully
527 dictates acute cognitive appraisals.

528 **4.3 Cognitive appraisal**

529 Cognitive appraisal in the TCTSA deviates from Lazarusian notions of cognitive appraisal in three
530 important ways. First, whereas the BPSM and the TCTSA express the importance of demand and
531 resource appraisals in challenge and threat states, Lazarus’ cognitive appraisal theory suggests that
532 challenge and threat emerge from primary appraisals of motivational relevance, and goal congruence.
533 Second, the TCTSA does not consider reappraisal in its network of psychophysiological responses. It
534 is possible to reappraise situations that have already been subject to cognitive appraisal (see Gross,
535 1998, for review). In other words, that which was once appraised as a threat can be reappraised as a
536 challenge, and vice versa. Third, in the TCTSA challenge and threat are the result of cognitive
537 appraisal, but for Lazarus (1999) challenge and threat are a part of cognitive appraisal, not the result.

538 In the TCTSA-R we propose a more parsimonious integration of Lazarusian ideas of cognitive
539 appraisal and challenge and threat, and the cognitive appraisal and challenge and threat concepts put
540 forth in the TCTSA. A recent critical review has proposed that challenge and threat states could be
541 simultaneously activated, this co-activation can accordingly lead to individuals appraising motivated
542 performance situations like sport as both a challenge, a threat, both, or neither (Uphill et al., 2019).
543 Although at this time there is no direct evidence that individuals can be challenged and threatened at
544 the same time, in our revision we consider that challenge and threat states are not static, and that
545 individuals can move from one state to another. This revision is important, because it reflects more
546 realistically and comprehensively the cognitive operations that take place when an athlete is

547 approaching a motivated performance situation. Specifically, we include primary appraisals
548 according to Lazarus (1999), and detail how an initial challenge appraisal could still lead to poor
549 performance through a perception of low resource appraisals as posited in the TCTSA through
550 reappraisal. Indeed, an athlete can evince a threat state but still perform well so long as they perceive
551 high resources (Turner et al., 2013).

552

553 4.4 The TCTSA-R

554 4.4.1 Primary appraisal

555 The primary appraisal “motivational relevance” will reflect the extent to which the competition is
556 personally relevant to the athlete’s goals. In addition, the primary appraisal “goal congruence” will
557 reflect the extent to which the conditions are favourable for their success. Challenge results from the
558 appraisal that the competition is highly relevant to the athlete’s goals, and that the conditions are
559 favourable for success. Threat results from the appraisal that the competition is highly relevant to the
560 athlete’s goals, and that the conditions are unfavourable for success. Challenge reflects the perception
561 that the athlete can bring the challenge to fruition. Threat reflects the perception that the athlete cannot
562 ameliorate the threat.

563 4.4.2 Demands vs Resources

564 Primary appraisal is not the end of the story. It is possible to make an appraisal of threat, but still
565 perceive that you have more than sufficient resources to meet the perceived demands of the situation,
566 and thus approach competition in a challenge state. Taken from the BPSM, demand appraisals comprise
567 perceptions of danger (physical and esteem), uncertainty, and the requirement of effort (physical and
568 mental). The demand appraisals are distinct from primary appraisals. That is, just because a
569 competition is appraised as personally relevant and incongruent with one’s goals (primary appraisal of
570 threat), does not automatically mean that the competition is also perceived as dangerous, uncertain,
571 and effortful (demand appraisal). In addition, even if the competition is appraised as highly demanding,
572 this does not automatically mean that a threat state will prevail, because the individual may perceive
573 more than sufficient resources to meet the perceived demands. That is, in light of primary appraisal
574 and demand appraisal, an athlete can still believe that they have the skills to succeed (high self-
575 efficacy), that they have control over those skills (high control), and that their social environment is
576 conducive to success (high perceived social support) (i.e. sufficient resource appraisals).

577 In contrast, it is possible to make a primary appraisal of challenge but also believe that you do not have
578 sufficient resources to meet the perceived demands of the competition, and thus approach the
579 competition in a threat state. That is, an athlete who appraises a competition as personally relevant and
580 *congruent* with one’s goals (primary appraisal of challenge), can also perceive high danger, high
581 uncertainty, and a high requirement for effort, and believe that they do not have the skills to succeed
582 (low self-efficacy), that they do not have control over their skills (low control), and that their social
583 environment is not conducive to success (low perceived social support) (i.e. insufficient resource
584 appraisals). In other words, the extent to which challenge or threat states dominate in anticipation of a
585 competitive situation is dependent on the primary appraisal of challenge and threat, the perceived
586 demands of the competition, and extent to which personal and social resources meet or exceed the
587 demands.

588 Therefore, the extent to which perceived resources meet or exceed demands could operate as a
589 bifurcation factor that dictates the affective, cardiovascular, and performance outcomes of the

590 competing athlete. That is, in the event of a challenge primary appraisal, high perceived resources
591 compared to demands is likely to help the athlete to fulfil their potential, whereas low perceived
592 resources compared to demands is less likely to help the athlete to fulfil their potential. Just because
593 the athlete appraises that conditions are favourable for their performance (challenge), their performance
594 is still in part dependent on how their resources compare to the demands of the competition. By
595 perceiving that resources sufficiently meet the demands, the athlete can bring the challenge to fruition
596 and execute their performance within the perceived favourable conditions. If challenge predominates,
597 it is then likely that a challenge CV pattern is evinced, alongside the recruitment of effective attentional
598 and motor skills required for successful skilled performance (fulfilling of potential). By perceiving that
599 resources do not meet the demands, the athlete cannot bring the challenge to fruition and cannot execute
600 their performance within the perceived favourable conditions. As a result, challenge cannot
601 predominate, it is less likely that a challenge CV pattern is evinced, and less likely that effective
602 attentional and motor skills are recruited, thus undermining the athlete's ability to fulfil their potential.

603 In the event of a threat primary appraisal, perceiving that resources exceed the demands of the
604 competition could also help the athlete to fulfil their potential, whereas insufficient resources could
605 significantly harm the athlete's performance. By perceiving that resources do not sufficiently meet the
606 demands, the athlete cannot ameliorate the threat and cannot execute their performance within the
607 perceived unfavourable conditions. If threat predominates, it is then likely that a threat CV pattern is
608 evinced, alongside ineffective attentional and motor skills recruitment required for successful skilled
609 performance (not fulfilling of potential). By perceiving that resources do meet the demands, the athlete
610 can ameliorate the threat and execute their performance within the perceived unfavourable conditions.
611 As a result, threat cannot predominate, and it is less likely that a threat CV pattern is evinced, and the
612 athlete is more likely to be able to recruit effective attentional and motor skills required for successful
613 skilled performance (fulfilling of potential).

614 Therefore, given that an athlete can make both challenge and threat primary appraisals, and can have
615 both high or low resources compared to perceived demands, we propose a 2x2 bifurcation theory of
616 challenge and threat, which reflect polychotomy of four parts; high challenge, low challenge, low
617 threat, high threat. Details of each are below:

618 **4.4.3 High challenge**

619 High challenge would occur in situations where the athlete perceives high motivational relevance
620 ("there is a goal at stake"), high goal congruence ("conditions are favourable for success") that results
621 in challenge. The athlete perceives sufficient resources to meet perceived demands. Specifically, the
622 athlete perceives high levels of self-efficacy, control, is focussed on approach goals rather than
623 avoidance goals, and has a high perception of available social support, and thus believes that they can
624 bring the challenge to fruition. In other words, they believe that they can make the most of the
625 favourable conditions in this important competition. As a result, the athlete is more likely to experience
626 positive emotions, if negative emotions are experienced, they are perceived as facilitative. The athlete
627 also evinces challenge CV reactivity resulting from a quick SNS response which quickly habituates
628 (cf. Epel et al., 2018). Athletes who respond in this state will also have greater levels of NPY and
629 oxytocin. Consequently, the athlete is more likely to experience helpful performance mechanisms and
630 is therefore likely to fulfil their potential in that competition.

631 **4.4.4 Low challenge**

632 Low challenge would occur in situations where the athlete perceives high motivational relevance
633 ("there is a goal at stake"), high goal congruence ("conditions are favourable for success") that results

634 in challenge. Specifically, the athlete perceives insufficient resources to meet perceived demands. The
635 athlete perceives low levels of self-efficacy, control, is focussed on avoidance goals rather than
636 approach goals, and has a low perception of available social support, and thus believes that they cannot
637 bring the challenge to fruition. In other words, they believe that they cannot make the most of the
638 favourable conditions in this important competition. Thus, the situation is perceived as favourable but
639 the personal resources are not. As a result, the athlete is likely to experience positive and negative
640 emotions, but perceives negative emotions are as debilitating. The athlete evinces challenge CV
641 reactivity to a lesser extent than when in high challenge. Although the athletes show challenge CV
642 reactivity, the SNS response does not habituate as quickly as under conditions of high challenge. It is
643 also proposed that athletes who respond in this state will also have low levels of NPY and oxytocin
644 reflecting in part, a low level of resources to meet the demands. Consequently, the athlete is less likely
645 to experience helpful performance mechanisms and is less likely to fulfil their potential in that
646 competition compared to high challenge.

647 **4.4.5 High threat**

648 High threat would occur in situations where the athlete perceives high motivational relevance (“there
649 is a goal at stake”), low goal congruence (“conditions are not favourable for success”) that results in
650 threat. Specifically, the athlete perceives insufficient resources to meet perceived demands. The athlete
651 perceives low levels of self-efficacy, control, is focussed on avoidance goals rather than approach
652 goals, and has a low perception of available social support, and thus believes that they cannot
653 ameliorate the threat. In other words, they believe that they cannot overcome the unfavourable
654 conditions in this important competition. As a result, the athlete is likely to experience negative
655 emotions, and perceive negative emotions as debilitating. The athletes evince threat CV reactivity and
656 the SNS response takes longest to habituate. Athletes in this group also have low levels of NPY and
657 oxytocin. Consequently, the athlete is likely to experience unhelpful performance mechanisms
658 (attention etc.) and is unlikely to fulfil their potential in that competition.

659 **4.4.6 Low threat**

660 Low threat would occur in situations where the athlete perceives high motivational relevance (“there
661 is a goal at stake”), low goal congruence (“conditions are not favourable for success”) that results in
662 threat. The athlete perceives sufficient resources to meet perceived demands. Specifically, the athlete
663 perceives high levels of self-efficacy, control, is focussed on approach goals rather than avoidance
664 goals, and has a high perception of available social support, and thus believes that they can ameliorate
665 the threat. In other words, they believe that they can overcome the unfavourable conditions in this
666 important competition. As a result, the athlete is likely to experience negative and positive emotions,
667 but perceive negative emotions as facilitative. The athlete evinces lesser threat CV reactivity than in
668 high threat. Whereas the athletes evince threat CV reactivity, the SNS response habituates quicker than
669 high threat. Athletes in this group will have high levels of NPY and oxytocin, reflecting their perception
670 of sufficient resources to meet the demands. Consequently, the athlete is less likely to experience
671 unhelpful performance mechanisms (such as attention) and is less unlikely to fulfil their potential in
672 that competition.

673 **4.4.7 Reappraisal**

674 It is important to clarify where appraisals fit within the TCTSA-R, especially in relation to demand and
675 resource appraisals. In essence, the demand-resource appraisal formula is part of a re-appraisal process
676 that takes place iteratively in light of changing contextual and cognitive information that could alter
677 both demand and resource appraisals (Cox, 1978; Lazarus, 1999). In reaction to a primary appraisal of
678 threat for example, athletes appraise the situational demands, and recruit resource appraisals to try to

679 ameliorate this threat, which in effect serves as reappraisal. Thus, primary challenge and threat
680 appraisals do not have to ‘define’ the approach to competition. Essentially, a threat appraisal can be
681 adaptive and welcome, and an athlete can still perform well, so long as they perceive high resources
682 compared to demands. This reappraisal means that an individual can re-appraise their initial challenge
683 or threat appraisal, and dictate the resultant approach to the competition as one of four states; high
684 challenge, low challenge, low threat, high threat.

685 In Lazarus’ (1999) cognitive appraisal theory there is more of an emphasis on secondary appraisals
686 when there is a potential for gain (threat appraisal), leading to either effective coping options (low
687 threat) or no, or ineffective coping options (high threat). There is, however, less emphasis on the
688 challenge appraisal, and it is seemingly assumed that the process ‘stops’ after the initial challenge
689 appraisal where it is appraised that there is a potential for gain or growth. This is also where the
690 TCTSA-R deviates from cognitive appraisal theory, we propose that after an initial challenge appraisal,
691 there is still a possibility for a threat state to dominate, as the resource-demands appraisal can steer
692 challenge and threat states as bifurcation factors (see Figure 1). Thus, we suggest that an athlete can
693 initially appraise a competition as threat, and after reappraising their demands and resources, either
694 challenge or threat dominates, but four states are possible. Similarly, after reappraisal, an initial threat
695 appraisal can lead to challenge *or* threat states.

696

697 -----Insert Figure 1 TCTSA-R around here-----

698

699 **5 Guidance for research and applied work**

700 Taking into account the revised TCTSA, the next step is to pose suggestions for research ideas and
701 applied implications. With these suggestions, it does need to be considered that the TCTSA is a
702 framework for managing stress (Turner & Jones, 2014), and therefore these suggestions are provided
703 within this realm, focusing on demands and resources.

704 **5.1 Suggestions for research directions**

705 We propose four broad suggestions for research moving forward, these are around measurement tools,
706 transparency of reporting the (physiological) data including standardized procedures and reporting for
707 physiological measures of challenge and threat, reconsideration of resources and social support, and
708 consideration of behavioural outcomes such as decision-making.

709 First, the review of the literature raised questions about the measurement approaches that have been
710 taken when measuring the physiological component of challenge and threat states; it is evident that
711 different approaches were taken, especially when considering the reactivity calculations. In light of
712 this, we encourage researchers to focus on considering the durations and time course of the
713 underpinning physiology when measuring physiological responses. Specifically, researchers should
714 assess blood pressure and haemodynamic measures for at least 3 minutes in the anticipation phase of
715 studies, following task instructions and any manipulation of challenge and threat. Moreover, we
716 recommend that cardiac output and total peripheral resistance are analyzed separately rather than
717 combined into a single index. We also advocate that researchers are transparent when reporting the
718 physiological data, and to consider that individuals can have blunted responses or are ‘non-responders’,
719 where participants show minimal reactivity (Wormwood et al., 2019) but may still perceive the

720 situation as a motivated performance situation. Therefore, we urge that researchers are more cautious
721 in their decisions as to who to include in their analysis and not, as well as reporting the means of raw
722 scores for the cardiovascular measures. From reviewing past research, it appears that outliers and non-
723 responders are frequently disregarded from the analysis, which can result in flawed conclusions. This
724 is important because it can affect findings and influences the replicability of research findings (Shapiro
725 et al., 1996; Sherwood et al., 1990). Assessing neuroendocrine markers of challenge and threat states,
726 such as cortisol, and NPY, may support our understanding of psychophysiological mechanisms, as
727 would exploring how parasympathetic nervous system activity can also relate to challenge and threat
728 (Laborde et al., 2015; Uphill et al., 2019). Preliminary evidence suggests that high frequency heart rate
729 variability can be linked to challenge and threat appraisal; Laborde et al. (2015) identified that,
730 compared to baseline, greater threat responses were associated with a decrease in parasympathetic
731 activity and Thornton et al. (2019) found increased HRV after challenge instructions compared with
732 threat instructions.

733

734 Second, the measurement tools used for the demand-resource ratio need consideration. One of the more
735 popular measures is the demand resource evaluation score (DRES; Tomaka, Blascovich, Kelsey, &
736 Leiten, 1993). The DRES uses two items from the cognitive appraisal ratio (Tomaka et al., 1993),
737 where one item assesses demands (“How demanding do you expect the task to be?”) and the other
738 assesses coping resources (“How able are you to cope with the demands of the task?”). Logically, only
739 the second question is valuable since it measures the perception that the individual has the resources
740 to meet the demands, regardless of how high the demands are scored. Other measures that have been
741 used are the recently developed Challenge and Threat in Sport (CAT-Sport) Scale (Rossato et al.,
742 2018), and eleven items (six assessing demands, five assessing resources) developed by Mendes, Gray,
743 Mendoza-Denton, Major, and Epel (2007) for experimental work. In addition, studies that more closely
744 align with the TCTSA assess the resources via separate measures of self-efficacy, perceived control,
745 and goal achievement (i.e. Meijen et al., 2013;2014; Turner et al., 2013). None of the aforementioned
746 psychometrics measure challenge and threat cognitive appraisals accurately in line with the TCTSA.
747 Therefore, clearly a valuable line of research is to develop such a measure and validity test it across
748 multiple sport participation levels.

749 Third, the role of social support in appraisal processes has received limited attention. Information about
750 whether a situation is to be perceived as a threat is frequently derived from others (e.g. Maratos, 2011).
751 Moreover, support as a resource might influence appraisal process in varying ways depending on
752 whether it is perceived or received, the type of support offered (e.g. instrumental or emotional), and
753 the source of support. For example, support from a coach might be more potent than that offered from
754 a friend or stranger, at least in some performance situations. There is some evidence that psychological
755 interventions are associated with larger benefits when they are delivered by coaches rather than
756 strangers (Brown & Fletcher, 2017). Whereas there is an extensive literature focusing on social support
757 and cardiovascular reactions to stress (e.g., Teoh & Hilmert, 2018), understanding how social support
758 influences appraisal processes or haemodynamic alterations in anticipation of performance would aid
759 our understanding of challenge and threat states.

760 Finally, we suggest that future research considers the outcome measures used and re-evaluate the
761 pathways used to measure performance. To date, most of the challenge and threat literature has
762 focused on overall sport performance indices. In only one study (Turner et al., 2012) was decision
763 making assessed through use of the Stroop task. Other decision-making tasks could be used to assess
764 system 1 (automatic and quick) and system 2 (diverting attention to effortful mental activities)

765 processes (Kahneman, 2011). For example, Simonovic, Stupple, Gale, & Sheffield (2017) found that
766 stress was associated with poorer Iowa Gambling Task and Cognitive Reflection Task performance.
767 Similarly, only one study has focused on (physical) power (Wood et al., 2018) as an alternative
768 outcome measure for performance; thus further studies of antecedents of overall sport performance
769 and their relation to challenge and threat states are encouraged.

770 **5.2 Applied suggestions**

771 The evaluation of the balance between demands and resources are at the core of challenge and threat
772 states, and therefore the guidance for applied work will focus on adjusting the demands and enhancing
773 the resources. As posed in the TCTSA-R one can still fulfil potential in low challenge appraisal, and
774 in high challenge appraisal you can still fail, therefore we focus on suggestions to help individuals to
775 develop what it requires to move to a challenge state.

776 **5.2.1 Changing demands**

777 One way of altering the demands is by implementing standardised protocols that are focused on
778 providing instructions that are related to uncertainty, potential for danger, and effort. Studies have
779 demonstrated that using protocols altering the demands of a sporting situation influence challenge and
780 threat states. These instructions have focused on informing athletes that their performance will be
781 compared to others, that they will be evaluated by coaching staff, and that their score is to be taken into
782 account for future team selections (Moore et al., 2012; Turner, 2013). Building on this, pressure
783 training (for example, see Stoker et al., 2017) can also be considered as a means to helping athletes
784 reduce the demands of a situation through the process of being more familiar with the situation and
785 thus reducing the uncertainty, potential for danger, and effort required. For example, in one study
786 (Turner et al., 2013) a pressured batting test was developed that emphasized the ego-threatening nature
787 of the task. Elite cricket athletes were instructed that a Batting Test would assess their ability to perform
788 under pressure, that they would be required to face 30 balls and attain 36 runs in order to be successful,
789 and that their total score would be compared to all other participants. The instructions also stated that
790 coaches would consider their performance in the Batting Test when making future decisions about
791 program selection, and therefore they would have to try very hard to perform well. The use of pressure
792 testing like the Batting Test may be a useful way of regularly and systematically introducing athletes
793 to pressure in a training context. Desensitisation research suggests that repeated exposure to these types
794 of activities could help athletes to adapt to stressful situations (Wolpe, 1973), thus becoming better
795 prepared for actual competitive pressure (Jones & Turner, 2014).

796 Altering task instructions can have implications for how coaches communicate with athletes, and
797 coaches can indirectly instigate a threat state when drawing on task instructions that are focused on
798 increasing the demands, but have an athlete who does not perceive to have the resources such as self-
799 efficacy or a sense of perceived control. What should also be considered is that changing the demands
800 is less within a person's control than enhancing cognitive resources. That is, one may rely on others,
801 such as a coach, to alter the environmental demands. Moreover, despite athletes experiencing a
802 cardiovascular reactivity pattern indicative of a threat, this did not always affect performance,
803 especially when these athletes have higher levels of self-efficacy (Turner et al., 2013). Considering that
804 self-efficacy, together with perceived control and approach/avoidance goals is a cognitive resource in
805 the TCTSA, we suggest adopting an applied focus that is more within an individual's control by
806 focusing on resources.

807 **5.2.2 Enhancing resources**

808 To develop cognitive resources such as self-efficacy, perceived control, and emotion control, practical
809 psychological skill interventions can be implemented, where a strategic focus is placed on enhancing
810 self-efficacy, perceived control, and emotion control through the implementation of psychological
811 techniques including imagery, goal-setting, concentration, and self-talk (Andersen, 2009). Findings
812 from challenge and threat research have demonstrated that imagery scripts can differentiate between
813 challenge and threat states (Williams et al., 2010) rather than just focusing on using imagery to
814 manipulate challenge and threat states, this can be built on to strengthen challenge states. Also, based
815 on the emerging evidence that irrational beliefs, as proposed within REBT, are related to greater threat
816 (Dixon et al., 2017; Evans et al., 2018), and that rational self-talk has been shown to increase
817 performance under pressure (Turner, Kirkham, & Wood, 2018), REBT could be applied with athletes
818 in order to promote rational beliefs, and subsequent challenge appraisals. Indeed, the use of REBT in
819 sport is growing (Turner, 2016), with some research finding that systolic blood pressure is reduced in
820 athletes following REBT (Wood, Barker, Turner, & Sheffield, 2017). Future research could examine
821 how REBT can influence challenge and threat states.

822 **6 Conclusion**

823 How individuals approach motivated performance situations in a competitive sporting environment
824 has been the focus of many researchers in the field of sport psychology and beyond. Reviewing the
825 research related to challenge and threat states inspired revisions to the Theory of Challenge and
826 Threat States. In particular, we suggest that NPY and oxytocin are also key indicators for facilitating
827 a challenge state. Moreover, we introduced a 2x2 bifurcation theory of challenge and threat reflecting
828 the polychotomy of high challenge, low challenge, low threat, and high threat. These revisions to the
829 TCTSA are intended to stimulate more research around measurement tools and reconsideration of
830 resources including social support. Finally, from an applied perspective, the revisions highlight the
831 potential for working towards a challenge state based on adjusting demands and enhancing resources.

832 **7 Author Contributions**

833 CM was responsible for the organization of the manuscript. CM, MT, MJ, DS, PM wrote sections of
 834 the manuscript, MT designed Figure 1, CM compiled Table 1, MT and CM reviewed the challenge and
 835 threat research. All authors contributed to the writing of the manuscript.

836 **8 Conflict of Interest**

837 *The authors declare that the research was conducted in the absence of any commercial or financial*
 838 *relationships that could be construed as a potential conflict of interest.*

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1195 **10 Table 1**

1196 Table 1

1197 *Theory of Challenge and Threat States in Athletes: Predictions made by Jones et al. (2009).*

	Prediction:	Supported/Partially supported/Mixed support/ Not tested
1	Demand appraisals relate to the perception and assessment of danger, uncertainty and effort required in a situation and stimulate an increase in HR	Supported
2	Athletes will experience a challenge state if their resource appraisals comprise high self-efficacy, perception of control and there is a focus on approach goals	Mixed support
3	Athletes will experience a threat state if their resource appraisals comprise low self-efficacy, low perceived control, and there is a focus on avoidance goals	Mixed support
4	A challenge response is characterised by an increase in SAM activation and the release of epinephrine and norepinephrine as indexed by increased cardiac activity and decreased TPR	Not tested
5	A threat response is characterised by increases in SAM and PAC activation and the release of cortisol as indexed by increased cardiac activity and either no change or increased TPR	Not tested
6	A challenge state will typically, but not exclusively, be associated with emotions of a positive valence	Partially supported
7	A threat state will typically, but not exclusively, be associated with emotions of a negative valence	Partially supported
8	Emotions experienced during a challenge state will be perceived as helpful to performance	Supported
9	Emotions experienced during a threat state will be perceived as unhelpful to performance	Supported
10	In a challenge state there is a need for less self-regulation and accordingly greater self-regulatory resources are available for the demands arising from the task	Partially supported
11	In a threat state anxiety will decrease the efficiency and effectiveness of cognitive functioning	Partially supported
12	In a challenge state anxiety will not lead to reinvestment	Partially supported

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13	A threat state will be associated with less engagement in the competition as an athlete uses avoidance strategies	Not tested
14	A challenge state will have a positive influence on decision-making	Partially supported
15	A challenge state will have a positive impact on anaerobic power	Partially supported

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